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OF THE STATE OF PENNSYLVANIA,

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THE REACTION BREAKWATER AS PROPOSED FOR THE OPENING OF THE SOUTH-WEST PASS OF THE MISSISSIPPI RIVER.

By LEWIS M. HAUPT, Member of the Institute.

INTRODUCTORY.

The Louisiana purchase of 1803 had for one of its objects the control of the outlet of the great central basin containing over 15,000 miles of navigable waterways, at a time when railroads were unknown.

Since 1837 the Government has made numerous desultory efforts to increase the depths at the delta mouths, which ranged from 8 to 15 feet, but without permanent results.

On May 3, 1875, after a protracted debate, Congress determined to depart from its usual policy and awarded a contract for the deepening of the South Pass to Capt. Jas. B. Eads for $5,250,000, on the condition of making payments

only as results were secured. After overcoming many difficulties in the face of persistent opposition, he secured a channel of 26 feet navigable depth and 700 feet surface width, which has been maintained to the present time, but this contract having now expired by limitation, and the dimensions of vessels having outgrown the channel, the problem of providing additional facilities is now demanding immediate and careful investigation.

On January 7, 1899, a Board of Engineers reported that "The following project, if executed with vigor, will, in the opinion of the Board, secure a navigable channel of adequate width and of 35 feet depth at mean low water of the Gulf of Mexico, throughout Southwest Pass of the Mississippi River, at a cost which is not excessive considering the vast commercial interests involved, and therefore in the opinion of the Board the proposed improvement is practicable."

Briefly, the plan consisted of two parallel straight jetties placed 2,400 feet apart, to extend from "about 30 feet of water" on the outer slope of the bar for about seven miles up the pass, making over fourteen miles of jetties in all, which with the levees, sills and auxiliary works were estimated to cost $13,000,000, while the estimate for jetty extension and maintenance was $390,000 annually, equivalent to another $13,000,000 at 3 per cent. In closing this report the Board remarks that "The plans described, therefore, are such as have been selected for the purpose of estimate, and should not necessarily be strictly adhered to unless experience shall fully justify them." "It is desirable that at least two powerful dredges be constructed at the beginning of the work, for use in forming and maintaining the required channel."

These plans, which were, therefore, regarded as merely tentative and designed mainly as a basis for an estimate, were referred back by Congress to a board of four engineers, "of whom at least two shall be from civil life; * * * said board of engineers shall submit detailed estimates of the cost of each and every feature of the project, and they shall report especially whether it is necessary to construct inner

jetties; and if, in their judgment, inner jetties should be constructed, they shall provide for the location of the same, so as to involve the least cost consistent with the safety and efficiency of the work hereby contemplated."*

This board reported, January 11, 1900, a radically different plan, "placing the main reliance upon dredging," and depending upon a "bottle or coffin"-shaped plan of jetties to aid in maintaining the channel. These jetties are to be divergent from the ends of the fast land, to be placed in shallow water remote from the channel, and to extend only to the outer 20-foot curve, all "for ease and cheapness of construction." "Their distance apart between centers varies from about 7,000 feet to a minimum of 3,000 feet. This width, even where it is least, is greater than has been heretofore deemed advisable * * * to take from them the duty of forming the channel."

In short, it would appear that the jetties will act to impound the silt in the vicinity of the channel instead of operating as a barrier to prevent its return after being pumped over, and are of no other use. Moreover, it seems that no consideration was given in this report to the quantity of silt the dredges would be obliged to handle, although it is stated that to create the desired channel would require the removal of some 22,000,000 cubic yards from the bar, and that two dredges could do this work in two or three years at a cost not exceeding 4 cents per cubic yard.† It was stated that the purpose of the modifications made in this second report was mainly to reduce the cost. The report, therefore, closes with the same recommendations as its predecessor, reserving the letting of the superstructure "until experiment and experience have developed the most economical methods of construction."

It would, therefore, seem that the problem is one that demands early consideration, and a solution which will give reasonable assurance of results within a cost which shall be fully justified.

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* River and Harbor Act, March 3, 1899.

† *Vide* p. 4, 56 Cong., 1st Sess., H. R. Doc, 329.

THE PHYSICAL PROBLEM.*

The possibility of securing and maintaining a deep-water channel at this pass can best be answered by a study of the

Proposed Government plan with two jetties and dredging.

Proposed reaction jetty without dredging for maintenance.

work done by the stream itself under its normal conditions, regarding it as an endless belt charged with sediment.

*Based upon the data furnished by the survey of J. A. Ockerson, C.E., member Mississippi River Commission, 1898.

If the favorable conditions existing in the pass can be reproduced on the bar in such manner as to create erosion instead of sedimentation and cause the deposition of the silt in a zone remote from the channel, the problem is solved in the best manner by utilizing natural agencies to carry its silt out of the pathway of navigation.

The usual method of improving the mouths of sedimentary rivers consists of the construction of two parallel jetties, at suitable distances apart, to confine the effluent until it reaches deep water on the outer slope of the bar. Such a method is effective, but it has the serious objection of recreating conditions at its mouth similar to those existing in a state of nature. The two jetties, acting as an aqueduct, must transport all the river sediment through the canalized channel and dump it in the sea at its mouth, trusting to the external forces to distribute it. This requires constant attention and dredging unless there be a strong littoral movement. Straight parallel jetties do not concentrate currents.

The modification proposed by the writer consists of a single curved jetty so located as to produce a reaction and scour across the entire bar in such a manner as to effect a lateral displacement of the material and the deposition of this silt on the opposite bank of the channel, where it will form a natural levee automatically adjusted to the regimen of the stream.

The probability of the success of this system can best be seen after a consideration of the physical condition of the stream and a careful calibration of the bar and channel.

PHYSICAL—THE BAR.

The form of the crest of the bar is an elongated ellipse having a semi-transverse axis of 3·5 miles and a conjugate axis of 1·9 miles. (See cut, Pl. 2.)

Its total perimeter from East Point around to the opposite bank is 7 miles.

The width of the bar between the 35-foot contours in the river and gulf is slightly over 3 miles and the ruling minimum depth of water is about 10 feet, extending over a length of nearly 2 miles measured along the crest.

PROFILE AND SLOPES OF BAR.

From a depth exceeding 40 feet, the bed rises 14 feet in less than 1 mile, or 1 foot on 360, thence it flattens in the next 2 miles to 1 on 690, running nearly level for several thousand feet and suddenly dropping off with an outer slope of about 1 on 12 to the 35-foot contour. Thence it deepens rapidly to over 70 feet within a half mile.

This profile is characteristic of a delta bar rolled seaward by a sedimentary river. All the material passing over it must first be dragged up the inner slope by friction or be carried in suspension by the ebb stream. With the bar removed the resistance to the transportation of sediment would be greatly reduced, and if a lateral instead of a longitudinal movement be imparted to it, the path will also be shortened and the work required of the current be still further diminished. In short, the bar would be rolled over laterally instead of being pushed out into the gulf in front of the jetties.

The longitudinal area of the profile of the bar above 35 feet depth, as it existed in 1898, was 265,375 square feet.

The length at bottom was about 16,700 feet, so that the mean depth of the deposit above 35 feet was 16 feet.

HYDROGRAPHY OF THE STREAM.

From the head of the pass to the outer 35-foot contour the distance is 19½ miles,of which about 15 miles are enclosed between two nearly parallel but low banks built by deposits from the stream. Beyond this point the process of bank-building is constantly progressing, but it is moulded and resisted by the exterior forces of tides, waves, winds and currents.

It should be noted, as the measure of the depths that the energy of the stream can maintain throughout the first 12 miles, that there is nowhere less than 45 feet along the thalweg of the channel, with occasional depths of 98 and 100 feet, while the mean cross-section between the first and eleventh mile is about 66,000 square feet and the average width is 1,511 feet, giving a mean depth of approximately 44 feet.

The quantity of discharge varies greatly at different seasons of the year, being greater in the spring; but taking the average at 200,000 cubic feet per second flowing through the mean cross-section, there will result a velocity of 3 feet per second (2 miles per hour), which is sufficient to move small stones of nearly 2 inches in diameter. It will not, therefore, permit deposits of sand or mud and is amply sufficient to maintain the sectional area.

The observed velocities varied from about 4·9 feet in May to 1 foot in August, when the discharge was least. It is also found that 41 per cent. of the entire discharge traverses the Southwest Pass; 9 per cent. the South Pass and the balance, or 50 per cent., the Pass á Loutre. But this 41 per cent., on reaching the gulf, where it is unconfined by restraining banks, expands externally and escapes over the bar through a section of 175,125 square feet, resulting in a mean velocity of a little more than 1 foot per second, with much lower bottom velocities. The mean depth, if uniformly distributed, would be 8·1 feet, but in consequence of the concentration due to inertia the actual depths at the apex of the bar are about 10 feet and on the flanks from zero to 3 feet. The width here is about seven times the normal width of the stream and no plan of improvement can be expected to permanently maintain the depths which does not provide for the approximate restoration and maintenance of this normal width and section.

If the width is materially enlarged it must be at the expense of depth, or the velocity will be greatly reduced and, in consequence, the rate of shoaling will be largely augmented by the effort of the stream to repair the violence done to its regimen.

THE ALIGNMENT.

But there are other agencies at work in the stream than mere volume and velocity which tend to create and maintain depths, as may be seen by a critical study of the location of the line of greatest depths with reference to the alignment of the axis of the river's bed, which have not received the attention their importance merits.

Thus, starting at the head of the pass, the river is practically straight for over 3 miles, with maximum depths diminishing, notwithstanding the contracting banks, from 76 to 58 feet. It then enters a curve to the right having a radius of 4·4 miles, which it follows for 2 miles, with depths increasing to 73 feet. Then comes a short straight reach of 4,000 feet, with depth decreasing to 69 feet, followed by a sharper curve to the left (nearly 3-mile radius), resulting in 91 feet depth at end of the seventh mile and a reverse curve to the right, of 5¼ miles radius, reaching over nearly 2 miles with 75 feet depths.

From this ninth mile the course is nearly straight to the bar, with widening banks and diminishing depths as follows: at the beginning of the tenth mile, 68 feet; eleventh, 57; twelfth, 52; thirteenth, 43; fourteenth, 36; fifteenth, 32; sixteenth, 38; seventeenth, 31; eighteenth, 21; at the end of the eighteenth mile, 15; eighteen and three-fourths crest of bar, 10; beginning of nineteenth, 15; of twentieth, 35; and of twenty-first, 93 feet.

Showing very conclusively the beneficial effects of curvature upon depth and maintenance of a channel of ample dimensions for navigation. The deepest water is found to be confined to the concavities in every instance, whilst even the crossings at points of inflection are not materially shoaled.

Hence it follows as a natural sequence that if, instead of permitting the effluent stream to discharge itself through a cross-section of 175,125 square feet, it be confined to one of about 70,000 or less, while at the same time the collateral bank is left open, as a weir, for surplus discharge, and if the reactionary forces be developed by a curve of normal radius, the results should be a reproduction of those existing in the stream above the bar and at a cost much less than that required to erect two parallel or other jetties.

Some idea of the enormous force which would be utilized by such a jetty may be ascertained from the following figures:

The main discharge is taken, as a basis of computation, at 200,000 cubic feet per second. The area of discharge

along the bar crest is 175,000 square feet. Of this, the single jetty would cut out 115,000 square feet or 66 per cent. (See cut.) If, therefore, this percentage of the discharge be deflected from its natural egress and be confined to the immediate vicinity of the guiding jetty, it would represent 133,000 cubic feet of water, weighing 3,700 gross tons, sweeping along the face of the work at the rate of 1 foot every second, in addition to the 66,000 cubic feet, or 1,850 tons, already traversing this same area.

This result would only be true, theoretically, if the velocities through every unit of the cross-section were uniform, which is not the case in practice; yet it is approximately correct, and serves to illustrate the great increment in concentration and discharge over a limited path which must result from this form of construction.

In other words, if, instead of only one-third, the entire discharge be voided over a limited sector of the bar, there must result a threefold increase in velocity or a triple increase in the water-section across that region of the bar.

The first result would be an increase of velocity, and the second the gradual enlargement of the section as its consequence; but these results would follow the development of the work as it proceeded, and hence there would be a rapid and simultaneous improvement depending upon the rapidity of construction, for as the resultant velocity increases by contraction due to the jetty extension, the section will be enlarged by scour due to this increase and localization of currents, thus tending to restore the velocity to its normal condition, and these agencies will operate simultaneously to create and maintain a normal cross-section and velocity after the completion of the work. The more quickly it is completed, however, the more economical and rapid will be the formation of the new channel.

As previously stated, every river possesses within itself both constructive and destructive forces; constructive where its energy is dissipated, destructive where it is concentrated.

It is for the engineer to use the one and reject the other according as he desires erosion or deposit, channel or bar.

Concentration of energy is caused by compression of currents; dissipation, by expansion.

Two parallel jetties do not compress, but merely train and direct the given quantity of water entering at their head.

A single concave curved jetty, so placed as to encroach gradually upon the path of a stream, however, does produce a compression causing reaction, deflection and deep erosion creating a channel parallel to its axis and building a natural levee by the lateral transportation of the displaced material.

If properly adjusted to a sedimentary delta bar, it converts dispersion into concentration, confining the energy of the outflow to the weakest section of the bar and produces a change of equilibrium in favor of the effluent stream. In short, it flanks the bar and opens the port.

Thus, this available energy of the stream, instead of being ignored, may be trained and applied to the carving out and maintenance of its own ample waterway for the benefit of commerce and industry.

INFLUENCE OF CURVATURE UPON DEPTH.

Every pilot and navigator understands that the deep-water channel hugs the concave bank, and every physical hydrographer has observed the same fact, whilst the engineering profession has been slow to recognize its cause or to make any practical application of this potent agent in the removal of shoals or the creation of channels.

Having in view their application, a few physical facts may be stated as fundamental principles:

(1) Rivers ignore straight lines and abrupt or angular changes of direction.

(2) The bed of the channel does not mould the stream, which is the living entity, so much as the stream moulds the channel, though they are closely related. The stream is the force, the bed the resistance as well as the resultant of that force.

(3) Bars are not found in the concavities of the bends, hence if a stream is made to bend over a bar the latter must disappear.

(4) Neither velocity nor volume constitute the most important factors in erosion, but the impact due to concentrating currents, continuously supported, or, in other words, a constantly maintained change of direction, causing reaction accompanied by lateral and vertical movements.

These agencies and effects have been carefully observed and studied of late years by some of the most distinguished and successful hydraulicians of Europe. A few of the conclusions reached by these authorities will be found in the appendix, as confirming these principles.

THE PROPOSED PLAN.

The jetty which will best fulfil the requirements of this problem is the one starting from East Point and extending nearly 2 miles in almost a straight line parallel with the axis of flow and at a proper distance from it, thence curving to the westward with a radius of about 4·64 miles for a little more than 2 miles and ending at the 30-foot outer contour.

The portion of the area of discharge which would be cut out by this jetty is 115,750 square feet, or 66 per cent., which deducted from the total area would leave 59,375 square feet or less than the normal section, but as the work would require several years to build and the volume of the movement would be confined to the outflow following the line of the jetty, the formation of the channel would be local, permanent and rapid. The 15,000 square feet of water section on the west flats would ultimately partially fill up and thus assist in confining the currents to the channel.

It is not the purpose of this paper to consider the details nor cost of construction.

BAR ADVANCE.

The comparative surveys since 1838 and 1898 show that during these sixty years the outer "35-foot" contour has moved gulfward about 3 miles, giving an average rate of 259 feet per annum, although the rate during the last quarter century was but ¾ of a mile or 176 feet per annum. The building of parallel jetties confining the silt to the outer slope

of the bar would undoubtedly greatly increase this advance; the bottle-shaped plan would create two bars, one outer and one inner, whilst the single curved jetty which would deflect material laterally over the ample shoals to the westward would retard it; but assuming that it were to advance at the rate of 100 feet per annum, it would require over fifty years to travel 1 mile, and the plan of the jetty is such that it would reach 7·4 miles before covering a quadrant, while, if found necessary, a tangent or reversal of curvature can be introduced in the distant future, as in the pass above, if thought desirable by remote generations.

DREDGING.

In his interesting review of the history of operations at the mouth of the Mississippi, Major Jas. B. Quinn, U. S. E., states that the first efforts consisted in stirring up the bottom with harrows, which were moderately successful in securing a slight increase. Then jetties were combined with the stirring-up process. This failed. The necessities for commerce grew, and yet with powerful dredging machines the maintenance of a channel with as little as 20 feet depth was ineffective. Surveys were made, boards reported, theories were fiercely debated, but they all ended in recommending larger appropriations.

Then came Captain Eads, and threw himself into the breach. He was most bitterly opposed by those who should have given him greatest encouragement. He risked his life and fortune, and finally opened a channel 30 feet in depth, disproving the ominous predictions of disaster and rapid bar advance by his success. "His perseverance under such adverse circumstances (says Major Quinn) was truly remarkable."

The first effort to open the Southwest Pass was made in 1837, by using an ordinary bucket drag. No improvement resulted, as a single storm obliterated all traces of the channel.

In 1852 $75,000 were appropriated to be expended by a Board of Army and Navy Engineers, who recommended the stirring-up process, and a contract was made for a channel

18 feet deep and 300 feet wide. This channel was maintained by harrowing and dredging for a whole year.

No further appropriations being made until 1856, the 18-foot channel vanished. Then $330,000 were made available. The contractors secured and maintained an 18-foot channel only so long as operations continued.

In 1867 another contract for stirring up was made for $75,000, but not executed. Then the "Government built a powerful dredge boat of special design, which was operated under the very best conditions," but it did not succeed in maintaining a much deeper channel than that formerly secured.

"Everybody was tired of the uncertain results secured by dredging on the bars," and the Fort St. Philip Ship Canal was proposed and estimated to cost $10,273,000. The only officer opposing it was Col. J. G. Barnard, U. S. E., who advocated an open-mouthed river.

Mr. Eads proposed to improve the Southwest Pass by jetties for $10,000,000. Ultimate depth, 28 feet. This led to a fierce controversy, resulting in Eads being required to accept the South Pass at a cost of $5,250,000.

The report of the Board, submitted January 13, 1875, recommended parallel dikes, with a view of obtaining a navigable channel of 25 feet, at an estimated cost for the South Pass of $7,942,110 and for Southwest Pass of $16,053,124.

The Board therefore recommended the South Pass as being entirely adequate and much cheaper. It stated:

"Its depth is 7 feet, and it discharges at its mouth about 22,000,000 cubic yards of sediment in suspension per annum," and added,

"These jetties should be 900 feet apart and run in straight lines parallel to each other to the 30 feet depth outside."

Fortunately, they were not built straight, but on a curve, gradually compounding to the westward, and ultimately still further contracted by spur dikes to reduce the width to about 700 feet.

The east jetty as built was 2⅓ miles long, and had a

radius at the outer end of a little over 2 miles (11,720 feet). The west jetty was about 1,000 feet distant, and had a radius of 15,000 feet.

The above digression will illustrate the difference between what was recommended and what was done, and serves to fill out the history.

Returning to the sediment and its removal by dredging, there is considerable range of opinion as to the amount of silt carried to the gulf through all the passes, but an average of the various statements made gives about 250,000,000 cubic yards per annum. This divided in the proportion of the flow through the mouths gives:

	Cubic Yards.
For the South Pass	22,500,000
" " Southwest Pass	102,500,000
" " Pass á Loutre	125,000,000

Any plan, therefore, which bottles up the natural escape for this enormous amount of sediment by two jetties and proposes to place its main reliance upon a dredging plant having a capacity much less than the annual sedimentation, must involve a herculean task, and would seem, in view of all past experiences, to be an interminable and enormously expensive problem.

On the contrary, the utilization of the energy of the stream by the interposition on the bar of a concave but stable resistance which leaves the right bank open for a natural adjustment of the regimen would appear to furnish the most economical and expeditious solution. It should be remembered also that the cross-section of the stream is more than double that required for navigation, so that if the new channel developed only 50 per cent. of the present section in the pass, it would still be more than sufficient.

CONCLUSIONS.

It would, therefore, seem to be a wise and rational policy to control the effluent stream at the Southwest Pass by a single training wall or jetty curving gently to the westward and reducing the area of discharge to that of the normal section with resulting mean depths of over 40 feet,

permitting the river to build its own counter-levee and to adjust its regimen to the new conditions without material advance of the bar seaward.

APPENDIX.

In his paper on "River Currents and Configuration of River Beds," read at The Hague International Navigation Congress of 1894, the author, L. Léliavski, a distinguished Russian engineer, said in substance:

"Parallel or nearly parallel lines look very well on the plan, but are in reality not applicable, as the idea on which they are based is in contradiction to the laws of movements of currents in rivers."

In works so constructed the channel is arbitrary and temporary, and often the reverse of what it should be.

There is no formula yet applicable to practice. The directions of water threads in a river are not parallel

"As the curves of the bed are stronger the more remarkable is the depth produced by a great pressure of water on the bottom caused by a convergence of the water threads towards the concave banks."

"Deepening increases not with the velocity of the current, but rather with the head of water working on the deepening and especially at an increased depth. The water, by its weight, does not allow the lower strata to pass over the irregularities of the bottom, but carries them away."

In the expression

$$\frac{M}{2}(v^2 - v_1^2)$$

much depends on the difference of velocity before and after impact; between v and v_1. If the obstruction be large and the current narrow, then $v - v_1$ is large and a considerable part of the mechanical power of the water is expended on the body to cause its removal.

"Therefore, to obtain the greatest difference of $v - v_1$, the radii of curves must be shortened."

"In projecting the trace of the banks we must principally follow the configurations of natural concave banks."

"Mere narrowing is not sufficient to remove 'crossings;' the threads must be made to take '*always a convergent direction*,' thus increasing v and M and diminishing v_1.

"All the molecules of a liquid body, having different velocities, describe curved lines, not parallel and not concentric.

"The head of water in the concave bank, by its pressure, causes the water to flow at the bottom in the inverse direction and obliquely to the banks.

"Material loosened in concavities is carried by the undercurrents, which distribute it in the direction of the opposite convex banks.

"The current converging towards a concave bank engenders by its shock an undercurrent in a direction lateral to the surface.

"The currents of the rapid channel draw the more sluggish threads towards it. In this way these threads arrive at the concave banks by the force of inertia, and partly also by the result of centrifugal force.

"The currents are not due to the form of the cross-section, but, on the contrary, the formation of the profile of the bed arises exclusively from the influence of their currents.

"The converging current causes longitudinal cavities which are especially deep in the curves and the bottom current rejects the soil from the sloping banks.

"The sharper the curve of the concave bank, the more rapid is the descent of the particle (of water) from the upper beds to the bottom, the greater is the power acquired by the movement and the greater the excavation of the bottom. The depth, therefore, varies inversely as the radius of the curve.

"The depth and constancy of the navigable channel are the effect of the converging currents. There must be room for the equal divergence of the bottom currents to admit of free circulation.

"There is no converging current at the inflections of the bed; there are, so to speak, not even banks.

"In order to have a considerable and stable deepening of the bed it is necessary to give the concave bank a regular form and a sufficient curve, and by an artificial lengthening

to conduct the water across to the concavity of the next reach which has to be treated in the same manner. With this treatment the inflections (crossing bars) of the bed disappear and we obtain banks alternately concave on each side. These banks may be designated conductors of the converging water-threads and of the channel."

At this same Congress, Messrs. Mengin, Lecreulx and Guiard reported their observations of similar phenomena. They say:

"Only observation of fact is of any real value.

"It is long known that concave banks produce deep pools, and all variations in curves of banks give rise to corresponding variations in depth. Clearly shown on the Garonne River. A general formula for the relation can hardly be stated for width, depth, speed, material.

"A local increase in width causes a shoal, although upon this same shoal the speed remains great and the bottom is unstable.

"If, abandoning the rectilinear form of bed, we introduce curves, the continuity of these curves becomes extremely important."

Thus these experienced practitioners would seem to confirm in every particular the principles and practice upon which the single reactionary breakwater is based.

THE GRAPHOPHONE GRAND.

[*Being the report of the Franklin Institute, through its Committee on Science and the Arts, on the invention of Thos. H. Macdonald, and embracing a general history of sound-recording and reproducing devices, with a supplement by Mr. Philip Mauro, Washington, D. C. Sub-Committee: Louis E. Levy, Chairman; Sam'l Sartain, H. R. Heyl and J. M. Emanuel.*]

HALL OF THE FRANKLIN INSTITUTE,

[No. 2063.] PHILADELPHIA, November 28, 1899.

The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the merits of the "Graphophone Grand," reports as follows:

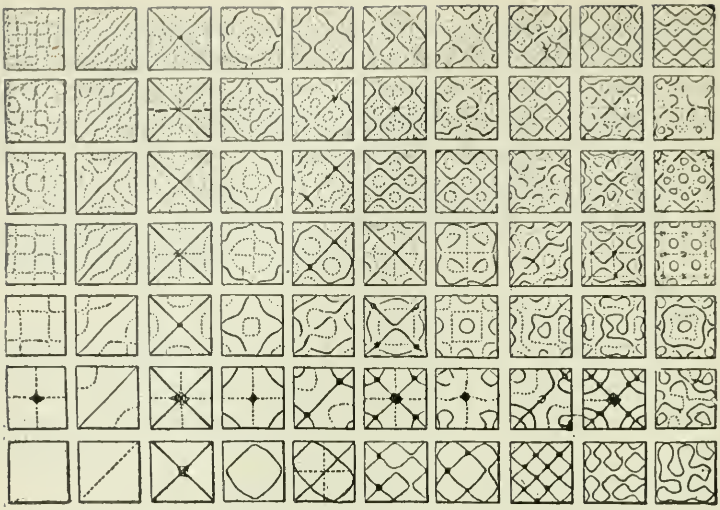

FIG. 1.—Chladni's figures.

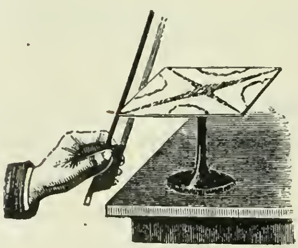

FIG. 2.

FIG. 3.

FIGS. 2 and 3.—Chladni's figures, showing symmetrical disposition of sand on plates vibrated with violin bows and dampened at various points.

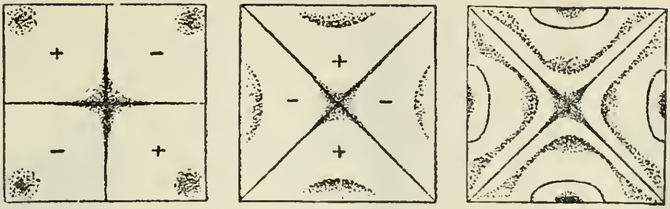

FIG. 4.
Strehlke's experiments on Chladni's plates, showing effect of mixing a very fine dust with the sand on the plates.

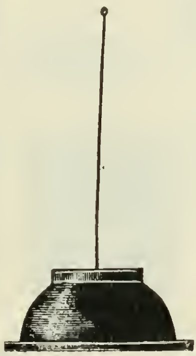

FIG. 5.—Wheatstone's kaleidophone.

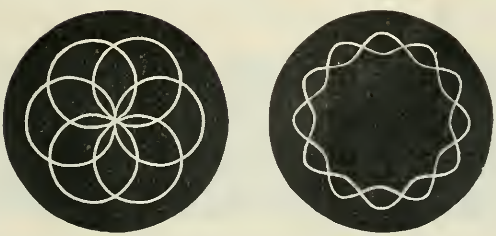

FIG. 6.—Kaleidophone figures.

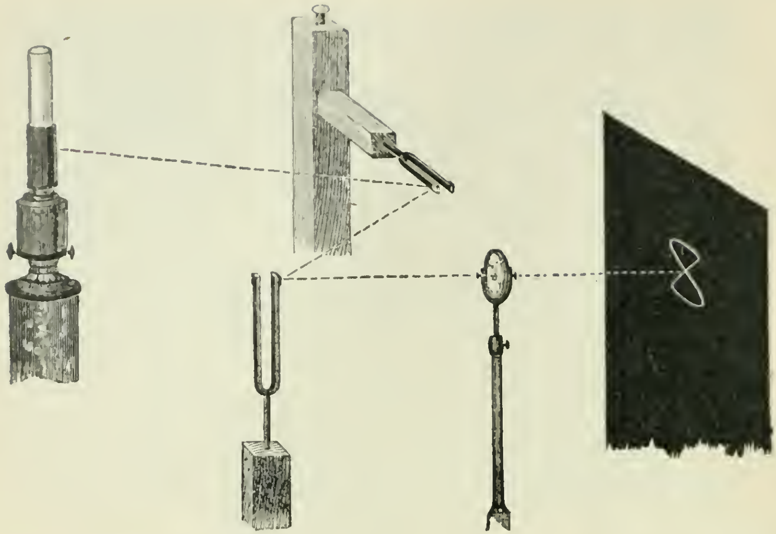

FIG. 7.—Lissajoux' apparatus for showing combined vibrations of two tuning forks at right angles with each other.

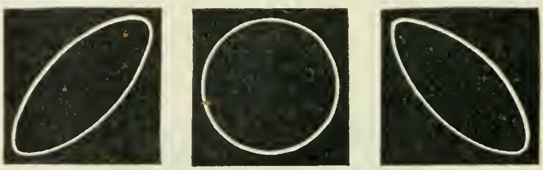

FIG. 8.—Luminous figures produced by two notes in unison.

FIG. 9.—Luminous figures produced by two notes an octave apart.

FIG. 10.—Luminous figures produced by two notes a fifth apart.

The subject-matter of this application is a method of recording and reproducing sound, invented by Thomas H. Macdonald, of Bridgeport, Conn., and termed the "Graphophone Grand." This method, as stated by Mr. Philip Mauro, in his presentation of the subject before the Franklin Institute (March 15, 1899), and also in the patent specifications, is a modification of and improvement on the method patented by Bell and Tainter in 1886. A proper understanding of Mr. Macdonald's improvement, accordingly, entails a due

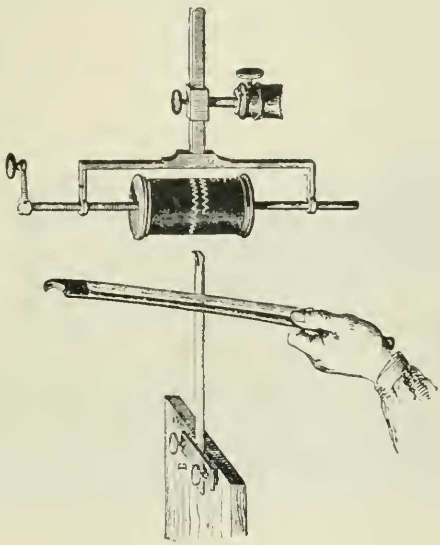

FIG. 11.—Graphic record of simple sound vibrations.

consideration of the earlier invention, and, coincidently, a review of the prior art generally.

Talking machines have been the aim of numerous inventors at least since, if not before, the year 1779, when the Imperial Academy of St. Petersburg offered a prize for the construction of a machine which should be capable of producing the vowel sounds as expressed by the human voice. The prize was awarded to Professor Kratzenstein, for his devices and investigations, which resulted in considerably widening the horizon of acoustic science, and presently thereafter the Abbé Mical in Paris (1783) and Von Krem-

pelen. in Vienna (1788) were working in the same field. Many ingenious mechanisms were constructed by these workers, and improved upon by various successors, of whom Faber, of Vienna, about 1850, produced a very remarkable speech-articulating machine. In 1857, however, the attention of inventors was directed to a more promising field of effort, through the labors of Leon Scott, who patented the sound-recording machine known as the Phonautograph, in which the principles of acoustic physics were employed to produce an autographic record of the human voice and of other compound sound vibrations.

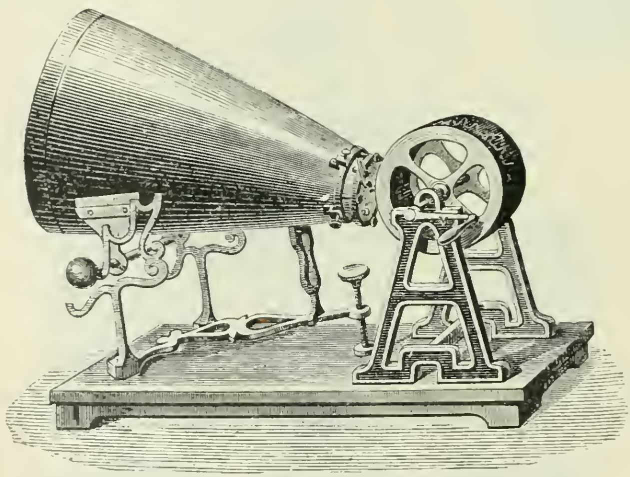

FIG. 12.—Leon Scott's Phonautograph.

The optical demonstration of rhythmic sound-waves dates back as far as 1787, when Ernst Chladni published at Leipzig his epoch-making discoveries in this field, but, although these developments were amplified by the researches of Strehlke in 1825, of Young and Wheatstone in the following decade, and by those of Tyndall, Helmholz, Melde and Lissajoux at subsequent periods, the graphic reproduction of vocal sounds appears to have been first effected by Scott's appliance. In that instrument the sonorous impulses produced by speech and other non-rhythmic tones were graphically recorded through the vibrations of a tympanum consisting of a flexible

diaphragm, acting by means of a stylus on a revolving cylinder, and it is this sensitive tympanum and its attached stylus, developed and improved by successive inventors, that form the essential elements in the talking machines of to-day.

The phenomena demonstrated by Scott were analyzed in relation to vocal sounds, and especially with regard to the separate functions of the vocal organs, by the French Linguistic Society in 1875, and these studies, together with Bell's invention of the telephone, in 1876, gave a new impetus to research in the direction of talking machines.

In the spring of 1877, the Paris Academy of Science appears to have received from M. Charles Cros a communication proposing the production of Scott's sound records in the form of tracings on a transparent surface, and the reproduction of these tracings by a photo-chemical etching

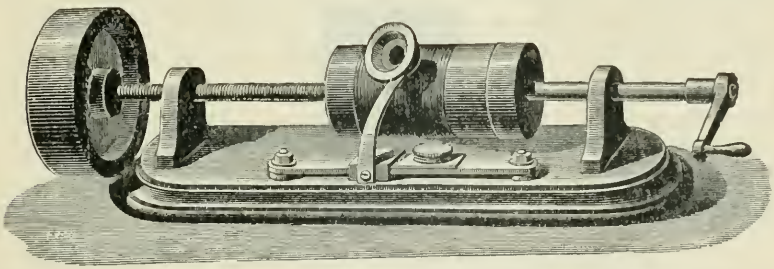

FIG. 13.—Edison's Phonograph.

process in the form of sunken lines on the record plate. In a retracing of the record, these lines were to serve as guides to the stylus, and thus the vibrations of the diaphragm, and, coincidently, the corresponding sound-waves, were proposed to be reproduced. A method analogous to this, but avoiding the intervention of photography, and producing the record directly on a plane metallic surface, was subsequently developed in this country (*infra*), but Cros appears to have gone no further than to make the communication referred to, which was not published in the *Comptes Rendus* until some six months later, in September, 1877.

In the same year, however, the actual reproduction of sound tracings back into perceptible sounds was accom-

plished by Thomas A. Edison, through his invention of the sound-recording and reproducing device termed the "Phonograph." In this instrument the movements of the vibrating diaphragm, which Scott had translated into the form of a sinuous line traced spirally around a cylinder, were reversed in their effect. Instead of the stylus being caused to move in a plane parallel with the surface of the revolving cylinder, it was made by Edison to indent the surface, and thus the sinuosities of Scott's line on an even plane were transformed into similar sinuosities of a line in a varying plane. This was done with a view to causing the stylus to retraverse the variously indented line, and thereby reproduce in the diaphragm the vibrations, and, coincidently, the original sounds, which had caused the indentations, and this effect was indeed produced in the mechanism which Edison devised for the purpose.

FIG. 14.—Section of tin-foil phonograph record.

The movements of the recording stylus being derived from the minute impulses of sound-waves acting on a membrane, Edison found it necessary, in order to produce an indentation sufficiently marked to serve the purpose of reproduction, to reduce to the utmost possible degree the resistance of the receiving material to the impact of the vibrating stylus. To this end, a thin grooved line was cut in a spiral around the receiving cylinder, and over this was fastened a sheet of tin-foil. By a suitable screw attachment the cylinder was revolved so that the spiral groove beneath the tin-foil passed under and in touch with the vibrating stylus, and thus the tin-foil was made to receive the impact of the stylus where the hollow groove in the cylinder left the foil without support. The indentations

produced in the tin-foil by the movement of the stylus were sufficiently positive and distinct to permit their translation into audible sound-waves. This was effected by causing the spiral line of indentation to repass before the stylus in contact with the latter, and thus to actuate the stylus as by a succession of cams and correspondingly to vibrate the diaphragm, which in turn transmitted its impulses to the surrounding air in the form of sound-waves corresponding to those which had produced the indentations originally. Edison's phonograph was thus the first strictly acoustic talking machine.

The very property, however, of the tin-foil, or of any similar material that afforded the possibility of its being sufficiently indented through the impulses of sound-waves, proved an insurmountable obstacle to its practical application for the purpose in view. A very few passages of the line of minute indentations in contact with the reproducing stylus sufficed to so far level down the spaces between the indentations as to practically obliterate the record, and though various means of giving permanence to the record were devised and put into practice, such as filling in with wax on the back, to stiffen it, or a reproduction of the surface by electrotyping, the technical difficulties encountered in these processes left the instrument unavailable for practical use.

Apart from various propositions to overcome this difficulty by causing a thin sheet of metal to vibrate in touch with a revolving cutting tool, in order to produce a sound record of durable quality, which does not, however, appear to have been actually attempted, the machinery of sound reproduction remained as Edison left it until 1886, when the efforts of Chichester A. Bell and Sumner Tainter, of Washington, D. C., afforded a solution of the problem. The advance effected by these two inventors consisted essentially in the substitution of a cutting edge for the indenting point of Edison's apparatus, and the coincident use of a material for their cylinders sufficiently cohesive to be practically available for reproduction and sufficiently amorphous to permit the cutting stylus to engrave its sur-

face. The substance which was found to answer these requirements best is a compound of beeswax and paraffine, which in practice was imposed on the surface of a cylinder of pasteboard. The stylus, having to cut into the surface of the recording cylinder instead of indenting it, was accordingly fixed at an angle to the radius of the cylinder, instead of parallel with it, and being held by a light spring or weight, in contact with the revolving surface, while vibrating under the impulses of the sound-waves, the vibrations were recorded in the waxy material in the form of an engraved line whose depth varied in accordance with the vibrating movements of the cutting stylus. These cuttings gave at once a record deep enough for reproduction and rigid enough to permit the repassage of the record in con-

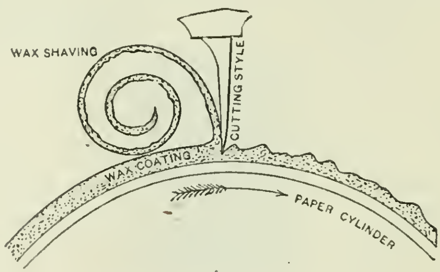

FIG. 15.—Cross-section of Bell and Tainter's graphophone record, showing process of cutting by stylus.

tact with the reproducing stylus a considerable number of times, without the successive elevations and depressions of the record being materially altered in their relations. In this regard the smoothness of the waxy ground afforded a material advantage. The positive nature of the engraved record, and the strength of the material in which it was made, afforded also the possibility of the records being mechanically duplicated on other cylinders by transmitting, through suitable connections, the motion of the recording stylus on the former to a cutter on the revolving surface of the latter.

Apart from the great advance effected by Messrs. Bell and Tainter in producing the sound records in a comparatively permanent and practicable form, they improved in

many important respects the various mechanisms required in the process. Their apparatus, in distinction from Edison's "phonograph," was called the "graphophone."

This historical review of the progress of sound-recording and reproducing mechanisms brings us, at this point in chronological order, to the consideration of another device for the same purpose, already alluded to, and which also may be regarded as starting from the phonautograph of

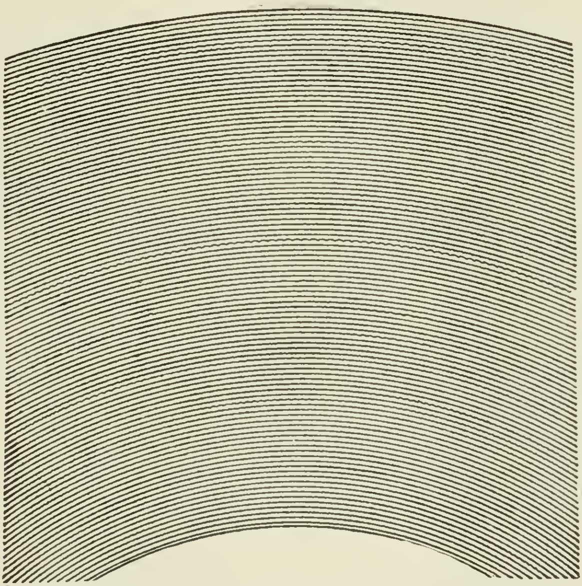

FIG. 16.—Section of Berliner gramophone record.

1857, but which, continuing on the lines of that instrument to obtain the record on a plane surface, diverged at this point and wrought this flat record into depressions by chemical means. These depressions, however, recorded the vibrations of the sound-receiving diaphragm in sinuosities of the side walls instead of sinuosities of the bottom of the lines. This was the so-called "gramophone," invented in 1887 by Emile Berliner, also a resident of Washington, D. C., and which was brought out before this Institute in May, 1888.

The principle of Berliner's procedure differs radically

from those of his predecessors, inasmuch as his record, being effected by a stylus vibrating in a plane parallel with the receiving surface, is free from the disturbances resulting from a varying resistance to its movements. This latter factor enters inevitably into the result when a depression of any surface is effected by indentation or by cutting, the resistance naturally increasing with the depth of the depression to be produced, while the latter is directly related to the amplitude of the vibration which the depression is to record. Berliner's record was traced in the form of a spiral line on the surface of a disk of polished zinc,

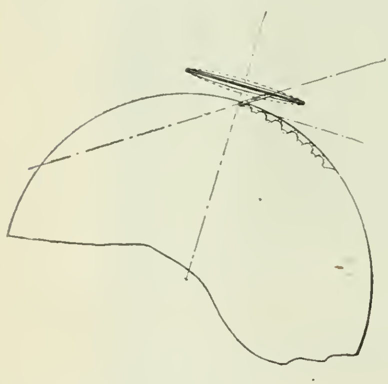

FIG. 17.—Section of graphophone record, showing condensed sinuosities.

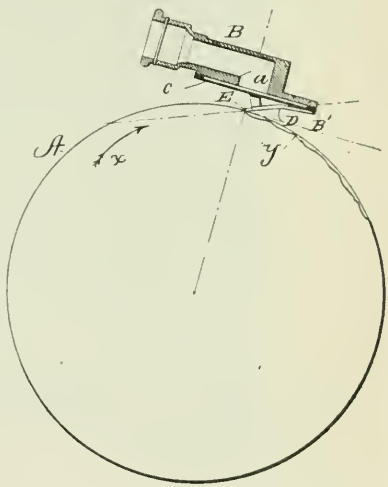

FIG. 18.—Section of Graphophone Grand record, showing extended sinuosities.

through a film of extreme tenuity, composed of a fatty acid obtained from a solution of wax. This film serves as a resistant to an etching mordant, which effects a depression of the traced line by erosion of the bared metallic surface, the etching then being ready for reproduction into sound-waves by reversing the procedure.

We now come to the latest innovation in acoustic mechanisms, the so-called "Graphophone Grand," as presented by Mr. Mauro. This invention, as has already been noted,

is a modification, by Mr. T. H. Macdonald, of the graphophone of Bell and Tainter. The improvement of the parent invention is effected (claim 1) "by imparting to the tablet a high surface speed, thereby forming undulations of great amplitude with long, gentle, easy strokes, as contradistinguished from a record of the same sound having short, abrupt undulations." Furthermore (claim 2), in the "placing of the vibratory cutting stylus in contact with a record tablet at an acute angle to the tangent at the point of contact."

With regard to these procedures, it appears from Mr. Mauro's presentation that there is no difference between the graphophone record of Bell and Tainter and that of Mr. T. H. Macdonald, except "that the recording tablet of the 'Grand' moves with a surface velocity of from two and a half to three times that given to the small tablet. The former is made large because, for practical reasons, it is preferred to obtain the high surface speed by increasing the diameter of the tablet rather than by increasing its axial speed."

With reference to these practical reasons it is noted in Mr. Mauro's presentation that "superficial considerations would indicate that such change in operation could only have the effect of producing a corresponding elongation of the undulations, and, in order to see a logical connection between the cause and effect, we must observe a little more closely the conditions under which records of sounds are made and reproduced." These conditions, it is stated, "may be roughly described as follows: The cutting stylus, performing its pendulous motion corresponding to the soundwaves, cuts a sinuous line composed of alternate elevations and depressions. As the cutting edge begins to descend to cut a depression, it at first encounters practically no resistance, the sharp edge alone being in contact with the material of the tablet; but, as the movement continues, the crest just being formed by the descent of the cutting edge comes in contact with the shank of the cutting stylus, that is, the smooth cylindrical surface forming the periphery of the stylus. As soon as this occurs a check is imposed upon the further penetration of the stylus, which is no longer free to follow

the movements of the atmospheric impulse. The effect of this check or damping influence is not merely to diminish the penetration of the stylus, but also to modify to some extent the form of the undulations.

"The effect of increasing the velocity of the recording tablet will now be easily understood. If that velocity be made sufficiently great, the crest of the undulations as they are formed are, so to speak, carried away so rapidly that they do not come into contact with the shank of the stylus at all. More exactly stated, the descending slope becomes a very gradual as distinguished from a very abrupt one, the curve approaching more nearly to parallelism with the recording surface. It follows that, the resistance or check being removed, the stylus will penetrate to a much greater depth than formerly, and will form undulations of much greater amplitude. The volume of sound being dependent upon the amplitude of the vibrations, the increased volume of sound is thus accounted for."

All this is quite true, but the utility of increasing the diameter of the cylinder to obtain the greater peripheral speed is not thereby made apparent. In a passage preceding the above quotation, it is noted that "when the speed is increased a proportionately greater amount of material is cut away in a given time, *i. e.*, more work is done and more resistance overcome during the period occupied by the utterance of a given sound. It would appear to follow that increased velocity does not diminish the resistance to the movement of the stylus, but just the reverse." It is clear enough that greater peripheral speed is desirable to the end of making the undulations of the incisions longer and correspondingly more gradual, but inasmuch as the length of the line and coincidently the extension of the undulations may be obtained on a smaller cylinder by increasing its peripheral speed, it appears certain that no gain in this respect is obtainable by the use of the larger cylinder. This conclusion is corroborated by a consideration of the element of resistance in relation to the angle of the cutting stylus to the tangent of the receiving cylinder. Immediately following the statement above quoted, Mr. Mauro notes as follows:

"The factor of resistance, however, has had an influence in determining the angle of inclination of the stylus to the recording surface and the shape of the cutting point. The latter is formed by a small cylinder of sapphire cut off in a plane nearly at right angles to the axis, so that the cutting edge is approximately an arc of a circle. With such a cutter the resistance to its action would be greatest when it operates in a position normal to the recording surface, and least when placed tangential thereto. This theoretical position of least resistance is, however, inadmissible in the operation of recording sounds. In this operation we have two movements to consider. The first is the straight-ahead movement of the tablet which results merely in the removal of the material in front of the cutting point and the formation of a groove. If the stylus were stationary during the operation it could, manifestly, and with great advantage, occupy a position almost tangential to the cylinder; but there is a second and all-important movement, namely, that due to the vibrations of the diaphragm, which movement is substantially radial of the cylinder. It would be manifestly impossible for the stylus to perform this movement at all if it occupied the ideal tangential position, for that would imply forcing the stylus sidewise into the hard body of the tablet, a task far beyond the strength of the feeble sound-waves. In practice, therefore, the stylus has been inclined at an angle of about 35° to the tangent at the point of contact."

Thus, it appears that the additional work imposed on the cutting stylus by the elongation of the line which it must cut is overcome by giving the cutting tool a sharper angle of incidence and possibly a sharper cutting edge. The added work entailed on the cutting stylus by the increased depth of the depression, obtained by freeing its shank from the back-hold of the preceding elevation, may be left out of account as being equivalent in work of the power lost in the back-hold. We have, therefore, to consider only the final element of the subject here presented, the position of the cutting stylus in relation to the tangent of the receiving cylinder.

It is plain (1) that the most efficient position of the cutting stylus would be in what Mr. Mauro recognizes as the ideal, that is, the tangential position; (2) that the smaller the diameter of the cylinder, the more nearly could the tool be brought to the tangential position without suffering the hold-back of the ridges in effecting the desired impressions.

Conversely, the highest position, that is, the largest angle of incidence required for freedom from back-hold, would be necessitated if a flat surface were to be incised by the tool, and inasmuch as the surface of a large cylinder offers more nearly the geometrical condition of a plane

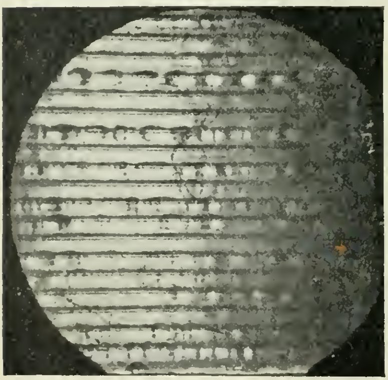

FIG. 19.—Reduced reproduction of ordinary graphophone record.

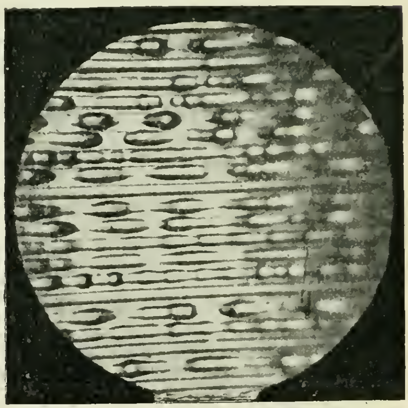

FIG. 20.—Reduced reproduction of Graphophone Grand record.

than that of a small cylinder, it follows that the efficiency of a cutting stylus, depending as it does on the acuteness of its angle of incidence, would be greater on a small than on a larger cylinder.

The possibility of obtaining a greater volume of sound by enlarging the characters of the sound record is noted by Berliner, in the *Journal of the Franklin Institute* for June, 1888. Mr. Mauro's statement that "methodical experiments have shown that beyond a certain critical speed there is no gain either in loudness or quality, but that,

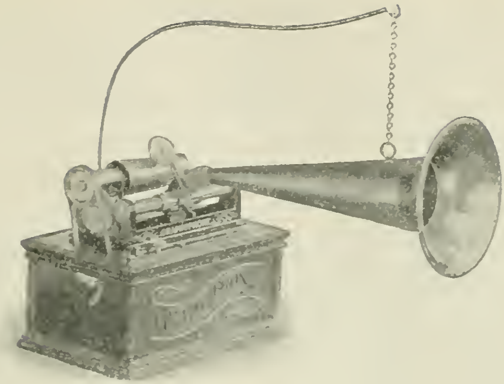

FIG. 21. -The graphophone.

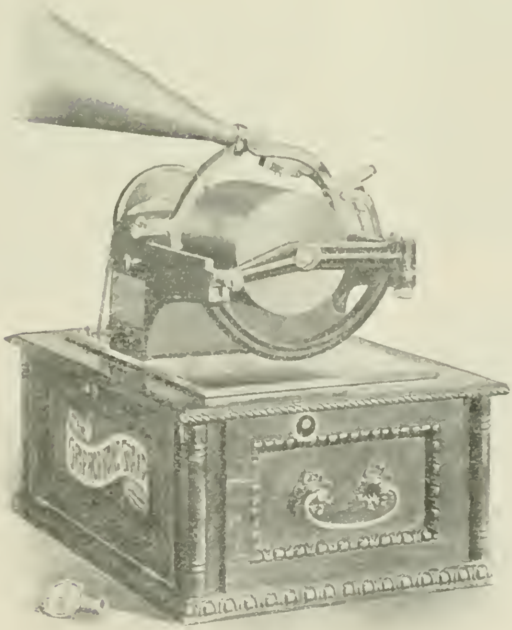

FIG. 22.—The Graphophone Grand.

on the contrary, the results deteriorate upon further increase of velocity," is in line with the previous observations of Berliner (Technische Notizen, etc., Leipzig, July, 1890), where, with reference to sound records on horizontal surfaces, it is stated "that the wave amplitudes increase up to a certain peripheral speed. Up to the present time this limit is reached at a velocity of 60 centimeters per second." This is equivalent to 36 meters per minute, while Mr. Macdonald stated it as being approximately 44 meters.

The utility of increasing the peripheral speed of a cylinder in which a sound record is to be incised is apparent in the greater gradation of the undulations and in the freedom from back-hold of the cutting stylus which these more gradual undulations afford. The embodiment of this utility in the Graphophone Grand is hereby recognized by the Franklin Institute, through the award to Mr. Thomas H. Macdonald of a Certificate of Merit.

In view, moreover, of the material advance effected by Messrs. Chichester A. Bell and Sumner Tainter in the development of sound-recording and reproducing mechanism, through their invention of the graphophone, the Franklin Institute recommends the award of the John Scott Legacy Premium and Medal to the said inventors jointly.

Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, January 3, 1900.

JOHN BIRKINBINE, *President.*
WM. H. WAHL, *Secretary.*

Countersigned by

EDGAR MARBURG,
Chairman Committee on Science and the Arts.

SUPPLEMENT.

RECENT DEVELOPMENT OF THE ART OF RECORDING AND REPRODUCING SOUNDS.*

By Philip Mauro,
Member of the Institute.

In the course of the commercial development of the art of recording and reproducing sounds, a notable result has recently been produced, which is of such a nature as to be of interest to science as well as to industry. It gives me great pleasure to present a brief explanation touching this new departure before this Institute, which has done, and is doing, so much for the encouragement of science and the useful arts.

The theory of making graphic representations of acoustical vibrations has long been familiar to physicists, but the practical application of that theory to the reproduction of audible copies of the original sounds was not brought within reach until the invention of the electric speaking telephone, in 1875, by Alexander Graham Bell.

The close relation between the telephone and the graphophone is obvious, and, as a matter of history, it was the existence of the former that suggested the first attempts at the reproduction of sounds from a prepared register of acoustical vibrations.

In the year 1877 Mr. Thomas A. Edison was occupied with experiments looking to the improvement of the telephone, and was one day testing with his finger the force of the vibratory movements of a telephone diaphragm. It then occurred to him that the characteristic form of these vibrations might be registered upon a pliable material by means of a point attached to the diaphragm. So far there was nothing original in his thought, for Leon Scott had, many years previously, devised an instrument (known to all physicists as the "phonautograph") whereby graphic representa-

* Read at the Stated Meeting of the Franklin Institute, held Wednesday, March 15, 1899.

tions of sonorous vibrations could be traced by means of a stylus in a film of lampblack, the stylus being carried by a vibratory diaphragm. But Mr. Edison's mind went further, namely, to the utilization of this registration or "record" to vibrate the same or a similar diaphragm, and thus produce sounds similar to those by which the graphic representation was made. The outcome of this idea was the tin-foil phonograph, with which every one is familiar, and which in the year 1878 attracted much attention, and gave rise to great expectations. To describe this instrument would be superfluous, but in order to give to later as well as earlier events their true significance, one or two facts with reference to it should be noted.

The method adopted was, theoretically, perfect; that is to say, the tin-foil phonograph was an attempt to embody the true conception that, if a diaphragm could be made by mechanical means to copy, even on a much reduced scale, the motions performed at a previous time by the same or a similar diaphragm when actuated by sonorous vibrations, reproductions of such vibrations would be attained. This theory was by no means new to physicists; but, prior to 1876, no mechanism capable of operating in conformity to it had been devised. What the telephone did for the kindred graphophonic art in that year was, mainly, to reveal the fact that a very small fraction of the force of the original sound-waves would suffice to actuate the repeating diaphragm, and to produce distinctly audible and recognizable sounds.

This was a fact of the most profound significance, and not likely to have been discovered by *a priori* reasoning. The force of acoustical vibrations is exceedingly feeble, and when attenuated by transformation (as in the telephone) into electrical energy, and back again into mechanical vibration, it is difficult, even with the evidence of our senses, to realize that the small residuum of energy conserved to the end of the series of operations is sufficient to give rise to audible sounds. This discovery demonstrated that the vibratory diaphragm could be made to do a certain amount of *mechanical work*, without such loss of energy

and without such distortion as to defeat the object of audible reproduction of the original sounds.

Mr. Edison availed himself of this newly discovered fact in his tin-foil indenting phonograph; and the desired and expected result was realized to the extent that sounds *were* produced with *sufficient loudness to be audible;* but disappointment was met in the fact that, somewhere in the series of operations, the characteristic *forms* of the vibrations were so lost or distorted that the reproduced sounds were but caricatures of the originals, and the reproduction of recognizable spoken utterance was not realized to a useful extent.

The questions how, where and why this loss and distortion occurred were extremely difficult of solution; and the literature of the subject, at that time, reveals no attempts to analyze or explain the result. At a much later day, and in the light which subsequent discoveries threw upon the subject, it became possible to understand why the Edison method of indenting or embossing a pliable material was and is incapable of accomplishing its intended object. The defects were of several sorts, but it is sufficient for our purpose to notice the main cause of failure, which was inherent in the method itself and quite independent of its mechanical embodiment.

For theoretical success this method required that the recording material be *perfectly mobile*, and capable of yielding, like a liquid, to all the complex movements of the recording stylus. On the other hand, in the operation of "reproducing," the material is required to have *sufficient rigidity* to actuate the stylus and diaphragm. Hence, the better a material answered to the requirements for *making* the record, the more unfit it was for *reproducing* the recorded sounds.

The failure of the phonograph was so pronounced as to discourage effort in the same direction for a long period of time. From 1879 to 1886 the literature of the art reveals no serious attempt to accomplish the reproductions of sounds, and no advance whatever was made during that period. Those were the seven years of famine in the art.

I have shown how, in one sense, the graphophone resulted from the telephone. I have now to show how this was true in another, and quite different, sense.

One of the acts for which the Emperor Napoleon I is commended even by his severest critics was the institution of the Volta prize, to be awarded by the French Government, upon the recommendation of the French National Academy of Sciences, for discoveries of great importance in electrical science. This prize was awarded in 1880 to Alex. Graham Bell for the discovery of the telephone; and he conceived the happy idea of appropriating the money part of the award to forming an association whose serious work should be the advancement of acoustical science. To this association, composed of himself, Dr. Chichester A. Bell and Mr. Charles Sumner Tainter, he gave the name "Volta Laboratory Association," in commemoration of the award.

The associates labored earnestly from 1881 to 1885, and as the result of their labors made many valuable contributions to science. Foremost among these was the method of recording and reproducing sounds, now in universal use, by *engraving a solid material of amorphous character*, such as wax or wax-like compositions. This system as a whole embodied many discoveries and inventions which contributed to the desired end and which cannot be referred to in detail within the limits of our available time. To mark the contrast with the embossing process it will suffice to notice (1) that, in the engraving method, the point of the stylus, which is a veritable graver's tool, is constantly *embedded in* the recording material, instead of merely *pressing on its surface*. Hence it acts constantly, as well during the backward as during the forward movement of the diaphragm, producing a *continuous* record without skips or breaks; (2) that the stylus removes the material by cutting it away, instead of merely displacing it, and that it does not disturb the material except at the *exact point of contact;* whereas the embossing stylus produced a depression and disturbance extending over a considerable area around the point of contact; (3) the engraving method resulted not only in accurate and recognizable records, but in records

that could be *removed from the machine*, handled and transported without detriment, and which could be used scores, indeed hundreds of times. This last-mentioned characteristic of the new graphophonic sound record is of the very first importance from the industrial point of view. Such was the graphophone as patented by Dr. Chichester Bell and Mr. Tainter in 1886.

Thirteen years have now elapsed, during which this great discovery has passed from the laboratory to the factory, and has become the foundation of an important industry. The incentive to improve the operation has induced inventors in large numbers to attempt it, and capitalists to lend their financial aid. Yet, save in details of mechanism and refinements of various sorts, everything remains as Dr. Chichester Bell and Mr. Tainter left the system in 1886. The main effort during this period has been for *greater volume of sound.* In this direction the art has been painfully struggling for many years, and the results have seemed to indicate that a practical limit had been reached.

But within a few months a new development has taken place, which produces results in volume of sound and in fidelity to the original, far exceeding the limits of what was previously, and by those best able to form an opinion, deemed possible.

What is of peculiar interest in this connection is the fact that the result in question is produced by an apparently slight variation from previous practice, and the attempt to trace the observed result from the apparent cause will form the concluding portion of my remarks.

It is appropriate at this point to offer a practical demonstration in order that your ears may judge of the extent of the advance that has been made. I shall first show you the result that has been attained by the standard graphophone, and from which a comparison can be made.*

The difference observable between the two machines before you (overlooking unimportant details of construc-

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* A demonstration was here given, using a record made by the old process and one of the same selection made by the new process.

tion), is that the cylindrical tablet of the loud-sounding machine is *larger* than that of the other. No one in this audience will for a moment suppose that the volume of sound is in any way affected by, or dependent upon, the *size* of the recording tablet. It would be as reasonable to suppose that characters written on a large piece of paper would be visible farther than characters of the same kind written on a small piece of paper. The other mechanisms are substantially the same in the two cases, that is to say, the same recording device is used, the same material for the tablet, and the same reproducer. The difference is that the recording tablet of the "Grand" moves with *a surface velocity of from two and a half to three times that given to the small tablet.* The former is made large because, for practical reasons, it is preferred to obtain the high surface speed by increasing the diameter of the tablet rather than by increasing its axial speed.

The known conditions, therefore, lead us to inquire how the mere increase in speed can bring about so remarkable a result. Superficial consideration would indicate that such change in operation could only have the effect of producing a corresponding elongation of the undulations; and in order to see a logical connection between the cause and effect we must observe, a little more closely, the conditions under which records of sounds are made and reproduced.

An important factor here is the *resistance* which the substance of the tablet offers to the action of the cutting style, which will conform absolutely to the movements of the acoustical vibrations only if absolutely free and unimpeded. This resistance is very slight, owing to the properties of the substance employed, which is an insoluble soap, and to the fact that a very sharp jewel point is used, whose normal penetration is not much more than one-thousandth of an inch, so that the style has to cut away an exceedingly small amount of a material having very slight cohesion. When the speed is increased a proportionately greater amount of material is cut away in a given time, *i. e.*, more work is done and more resistance overcome, during the period occupied by the utterance of a given sound. It would appear to

follow that increased velocity does not diminish the resistance to the movements of the style, but just the reverse.

The factor of resistance, however, has had an influence in determining the angle of inclination of the style to the recording surface and the shape of the cutting point. The latter is formed by a small cylinder of sapphire cut off in a plane nearly at right angles to the axis, so that the cutting edge is approximately an arc of a circle. With such a cutter the resistance to its action would be greatest when it operates in a position normal to the recording surface, and least when placed tangential thereto. This theoretical position of least resistance is, however, inadmissible in the operation of recording sounds. In this operation we have two movements to consider. The first is the straight-ahead movement of the tablet, which results merely in the removal of the material in front of the cutting point and the formation of a groove. If the stylus were stationary during the operation it could manifestly, and with great advantage, occupy a position almost tangential to the cylinder. But there is a second and all-important movement, namely, that due to the vibrations of the diaphragm, which movement is substantially radial of the cylinder. It would be manifestly impossible for the stylus to perform this movement at all if it occupied the ideal tangential position, for that would imply forcing the stylus sidewise into the hard body of the tablet, a task far beyond the strength of the feeble sound-waves. In practice, therefore, the stylus has been inclined at an angle of about 35° to the tangent at the point of contact.

Under these conditions, what takes place in the operation of making a sound record may be roughly described as follows: The cutting stylus, performing its pendulous motion corresponding to the sound-waves, cuts a sinuous line, composed of alternate elevations and depressions. As the cutting edge begins to descend to cut a depression, it at first encounters practically no resistance, the sharp edge alone being in contact with the material of the tablet; but as the movement continues the crest just being formed by the descent of the cutting edge comes in contact with the

shank of the cutting stylus, that is, the smooth cylindrical surface forming the periphery of the stylus. As soon as this occurs a check is imposed upon the further penetration of the stylus, which is no longer free to follow the movements of the atmospheric impulse. The effect of this check or damping influence is not merely to diminish the penetration of the stylus, but also to modify to some extent the form of the undulations.

The effect of increasing the velocity of the recording tablet will now be easily understood. If that velocity be made sufficiently great, the crest of the undulations as they are formed are, so to speak, carried away so rapidly that they do not come into contact with the shank of the stylus at all. More exactly stated, the descending slope becomes a very gradual as distinguished from a very abrupt one, the curve approaching more nearly to parallelism with the recording surface. It follows that the resistance or check being removed, the stylus will penetrate to a much greater depth than formerly, and will form undulations of much greater amplitude. The volume of sound being dependent upon the amplitude of the vibrations, the increased volume of sound is thus accounted for.

Methodical experiments have shown that, beyond a certain critical speed, there is no gain either in loudness or quality, but that, on the contrary, the results deteriorate upon further increase of velocity.

The improvement in quality resulting from this new method is apparently due to the fact already stated, namely, that the diaphragm and cutting stylus are at all times free to move in accordance with the acoustical vibrations. The test of the ear convinces us that the records made by this process correspond very closely to the form and amplitude of the actuating vibrations. But in all probability they correspond more closely than that test would indicate, for the conclusiveness of that test would imply a perfect-acting reproducer. It is appropriate, therefore, to notice the construction of the reproducer and the conditions under which it operates. It will appear from this examination that the operation of reproducing the recorded sound is materially affected by the invention under discussion.

The reproducing stylus has an end of spherical curvature which rides in the record groove, being automatically held therein by the weight of the mounting of the reproducer, which is supported on a universal joint.

The object sought is to give to the device such weight that the stylus will at all times rest in the record groove and follow accurately the undulations thereof. With the low-speed record it could not do this. The crests, when very close together (as in high-pitched sounds), did not afford the point (which must have a relatively large area in order not to cut the record) opportunity to descend fully into the intervening depressions. Moreover, when an abrupt ascending slope impinged against the reproducing point, the effect was that of a blow, throwing the point away from the record and causing an interruption of the operation. With the gentle slopes and wide curves of the high-speed record this irregularity is largely eliminated, and we approach much nearer to the theoretical condition for perfect reproduction, namely, that the diaphragm should be at all times controlled by the sound record, and should move in strict accordance with the form of its undulations. Not the least remarkable and interesting fact connected with our subject is that the discovery of a relation between the velocity of the recording material and the volume and quality of the reproduced sounds has so long escaped attention. It appears strange indeed that, with so many observers and with so strong an incentive to increase the volume of sound, this simple law has not sooner been discovered. It seems, however, that variations of speed within ordinary limits produce no noticeable difference, and obviously, other things being equal, it is desirable to use as low a speed as practicable, and thus obtain a record of maximum length upon a surface of given area.

The credit for this interesting discovery and for its embodiment in operative mechanism is due to Mr. Thomas H. Macdonald, of Bridgeport, Conn.

ELECTRICAL SECTION.

Stated meeting held Tuesday, April 24, 1900.

ELECTRICAL MEASURING INSTRUMENTS.

BY J. FRANKLIN STEVENS.

In attempting a brief discussion of so broad and comprehensive a subject as that assigned me for this evening, I have been principally concerned in trying to decide just what portion of the general subject I should touch upon and in what manner I could treat that portion briefly, for I cannot hope to be comprehensive, and yet have my remarks present a semblance of coherence.

Since we have available a very extensive literature bearing on the subject of laboratory testing instruments, in which can be found descriptions of the instruments employed, their construction, application and approximate laws, I shall pass over that portion of the subject and confine myself to commercial direct reading indicating instruments, such as are to be found in every-day use.

The history of the art embodied in the commercial manufacture of indicating instruments is extremely interesting, but shows many analogies to the development of other branches of electrical engineering, with the single exception that practical data in published form is extremely scarce. Every one entering this field is compelled to master some of the most intricate problems known to the profession, and must learn for himself how best to apply theoretical deductions to practical mechanical devices. Until very recent years, our sole guide has been the study of early and primitive types which in their time were useful and valuable, but which to-day fail to reach the high standard we have learned to demand of an instrument whose function is to indicate the input or output of our many and varied electrical devices. Every new device put before the public has meant a new condition to be met by the instrument manu-

facturer, requiring of him a new design or modification of an existing design. Two rather recent examples of this occur to me: one, the increasing tendency to employ high voltages in commercial work, reaching frequently 12,000 volts in the case of series constant-current arc light systems and 33,000 volts in long-distance power transmissions; the other, the rapid development of the electric automobile, which requires a volt-ammeter of as high a degree of accuracy as the portable laboratory instrument, yet able to withstand the roughest usage ever accorded an instrument of precision, coupled with restrictive specifications as to size and weight. In every instance instrument manufacturers have met the demands made upon them better, I think, than many of our fellow-workers have in some other lines. Much yet remains to be done, and much, I am confident, will be done in the matter of perfecting existing instruments in the near future. Gradually inefficient or unreliable types are being relegated to oblivion, and the remaining ones brought closer and closer to standard uniform construction.

The greater number of measurements required to-day can be made with a voltmeter, ammeter and wattmeter, and, while it might be thought that the wattmeter is merely a combination of the voltmeter and ammeter mounted in one case, this is not true in all classes of measurement. While it is true that the reading of the wattmeter represents the product of the readings of the voltmeter into the ammeter in the case of direct current measurements, it is not true in the case of alternating current measurements, save in the very exceptional case of a circuit possessing neither capacity nor inductance or a balance of the two. When either inductance or capacity exist there is a consequent lag or lead of the current wave relative to the pressure wave, and, since the instantaneous readings of the volts and ampères represent the mean effective or virtual values, that is, the square root of the mean square, their product differs from the reading of the wattmeter, which indicates the integrated values of two curves, the maximum and minimum values of which occur at different times. To obtain an agreement

between the values obtained by volt-ampère readings and watt readings, it is necessary to multiply the volt-ampère readings into the cosine of the angle of lag or lead, so that the ratio of the watt readings, as given by a properly constructed wattmeter, to the volt-ampère readings gives us the power factor of the circuit, and from the two sets of readings we can readily determine the angle of lag or lead and the so-called wattless current. Probably this is well known to all of you, yet scarcely a week passes but I have to explain the matter to one or more customers who cannot reconcile the difference in the two sets of readings and are inclined to believe that some, if not all, of their instruments are indicating erroneously.

Before touching on the different types of indicating instruments which are most commonly found in commercial use, let us consider for a moment the essential requirements of a practical and satisfactory instrument for measuring voltage, current or power. To start with, the instrument must be direct reading. We have no time to-day to convert angular deflections into true values by means of tables of constants, but insist that the pointer shall indicate directly in definite units the value of the passing load or the impressed electro-motive force. We must next be assured of the accuracy of the calibration, and for that depend principally upon the reputation of the maker or check the indications by comparison with a secondary standard. Beyond this we must know that the accuracy of the indications is not affected by the influence of ordinary external fields or by normal variations of temperature, due either to heating within the instrument, by means of the passage of the current to be measured, or to variations in the temperature of the room in which they are installed. All instruments should be mounted in dust-proof cases, and the systems carried in jewelled bearings; the movement of the pointer should be aperiodic or dead-beat, and, so far as possible, the system should contain nothing subject to change or deterioration, and should be constructed so that it will withstand successfully the ordinary rough usage liable to be accorded it in practice. The question of gradual change of accuracy,

due to the change in some constituent part of the system, has led me to strongly advocate the use of electro-magnetic instruments with gravity control for switchboard use whenever the conditions render them applicable, and I fully expect to see this type of instrument become more popular as its advantages become more widely appreciated. Such a system is not applicable for portable instruments, save the dynamometer system for alternating currents, and even then a spring control must be used; nor is the series electro-magnetic ammeter practical above about 1,500 ampères, due to the structural difficulties involved in carrying the bus bars directly to the instrument terminals. The one objection most commonly urged against the electro-magnetic instrument for direct current switchboard use is the unequally divided scale, for, as a rule, the scale only covers a range starting at 10 per cent. of the total up to maximum. In most cases, however, this objection is purely captious, for a switchboard voltmeter is seldom used to indicate more than 10 per cent. above or below the normal voltage, and the ammeter indications are of principal importance in the higher ranges to prevent a possible overload of the circuit or generator. In alternating current circuits an equally divided scale is an impossibility, so why should we sacrifice constancy in direct current measurements for the sake of an equally divided scale when the lower registers are so seldom used? In portable direct current instruments the proposition is somewhat different, as we desire to cover the maximum limits of possible measurement on a single scale instrument; therefore, an equally divided scale is desirable and practically necessary.

Taking up now the different types of instruments which are in most common use, we find they may be roughly divided into six classes, depending on the principle by means of which measurements of voltage, current or power are made: (1) the hot-wire; (2) the tangent galvanometer; (3) the electro-static; (4) the dynamometer; (5) the D'Arsonval galvanometer and (6) the electro-magnetic.

The hot-wire instrument is designed to operate by the expansion of a fine wire or strip of conducting material

due to the heating produced by the passage of the current to be measured, and, therefore, the indications are proportionate to the square of the current. This type of instrument possesses the advantage of indicating with equal accuracy the current flow on either direct or alternating current circuits and is independent of the frequency of the circuit or of the shape of the current wave; it is, further, unaffected by the presence of external fields. These advantages, however, are all that can be claimed for this system, and to offset them are many serious disadvantages. Since the instrument operates by virtue of temperature differences, it is extremely susceptible to variations of external temperature, and such variations must be compensated either by mechanical means, which provide for bringing the pointer to zero by increasing or decreasing the tension on the working wire, or by providing auxiliary heating strips which are supposed to automatically adjust the tension of the working wire on the general principles of a thermostat. This may seem a small matter to most observers, but to me it signifies an error in principle, and reminds me of one of our early types of arc dynamos which, by reason of incorrect construction, was found to spark badly; so, in place of correcting the design, an air blast was provided to blow out the spark. Another point of objection is the constant change of zero, due to the fact that until the wire has been stretched to its elastic limit it will fail to return to the same point after having been stretched by the heat applied and will always show a slight residual strain. To attempt to correct this prior to installation in the instrument means, judging by my own experience, that at least 90 per cent. of the wires will break during the preliminary stretching process, and the remaining 10 per cent. will stand but a very slight overload in service. As overloads are quite common, this would constitute a serious objection, for it means the return of the instrument to the manufacturer for the insertion of a new wire and recalibration. Another very serious objection is the amount of current required to operate the instrument. The average resistance of a modern hot-wire voltmeter is 4

ohms per volt, which means a current flow of ·25 ampère. This low resistance effectually bars this type of instrument for accurate testing, since the amount of power abstracted from the circuit to be tested vitiates the accuracy of the results obtained and introduces serious errors, which must be allowed for in all calculations. Recently an attempt has been made to introduce the hot-wire instrument as a shunt ammeter, particularly for alternating current measurements. As a shunt ammeter, the hot-wire instrument is a distinct failure, for, while the manufacturers claim it can be operated on a drop of ·3 volt for full scale, my personal experience has shown a drop of 6 volts to be necessary. On the makers' figures, 300 watts would be required to operate a 1,000 ampère ammeter, nearly ·4 horse-power per instrument, while on the sample I have tested 6,000 watts, or 8 horse-power, would be required. Again, it has been shown that these ammeters when calibrated on direct current are not accurate within 10 per cent. when used on alternating currents, unless the reactance in the shunt is exactly equal to the reactance in the instrument, a condition almost impossible to obtain, even with the most careful design.

A modification of the hot-wire system has been proposed, consisting of an enclosed chamber containing a fixed resistance wire, one end of the chamber, which is made air-tight, consisting of a flexible diaphragm operating the pointer through a system of levers. In this case, the heat supplied to the wire by the passing current causes the air in the enclosed cylinder to expand and, consequently, puts the diaphragm under tension, very much on the principle employed in the aneroid barometer. I find by actual experiment that such a system could be applied to voltmeters, and could be so made that it would be accurate in its indications and would possess a reasonably high resistance. The feature, however, which renders this system impracticable is the slowness with which the readings can be taken. The pointer will not come to rest until after the heat supplied the air enclosed within the chamber is equal to the heat radiated by the walls of the enclosing chamber, and from

one and a half to two minutes are required before the pointer will come finally to rest at the part of the scale marked to indicate the impressed E.M.F. This is true no matter how small the air chamber is made; and while it is possible to shorten this time by carefully covering the sides and one end of the cylinder by a heat insulating jacket, still it cannot be constructed so as to give an instantaneous reading, and every attempt to shorten the time by covering the walls of the chamber results in a corresponding increase of the time required for the pointer to come back to zero after current has been shut off. In other words, the instrument is similar in its action to an ordinary thermometer, which, as you know, cannot be made to respond instantly to changes of temperature.

Electro-static instruments, which depend for their action on the mutual attraction of two plates connected to the opposite sides of the line, are still used, but not extensively, for high tension measurements. They will indicate correctly on either direct or alternating current circuits, but are limited to measurement of voltage. It is impossible with this type of instrument to obtain a low reading, as the attraction of the plates toward one another varies approximately with the square of the potential difference between them. I say "varies approximately" advisedly, as the capacity of two plates varies directly with the square of the voltage only when the distance between the plates is maintained constant, which in this case is an obvious impossibility. As a rule, these instruments cannot be made dead-beat without introducing elements liable to seriously interfere with their accuracy; and, while there are no errors due to temperature changes, and while they are also extremely efficient, requiring no current flow at all, they are affected very considerably by external influences, particularly by static charges, which are almost invariably present in power stations or dynamo rooms, and, as you probably know, it is practically impossible to provide a shield for static effects.

Instruments employing the principle of the tangent galvanometer are still employed, and for certain classes of

measurements are extremely useful. They can be particularly recommended for use as ground detectors or differential voltmeters, where the actual value of the indicators is of small moment, the particular object being to show a balance of two opposing voltages or the presence of a ground by deflection. In this system the magnetized needle is suspended vertically, and is acted upon by two equally and oppositely wound solenoids; that is, the solenoids are wound with two wires in multiple and then cross-connected, so that we have two circuits equal in effect but opposite in action. I might say in passing, that if the proper proportions of solenoids to magnetized needle are employed, and the length of the magnetized needle properly proportioned to its area, the tangent galvanometer instrument may be made extremely accurate and also quite permanent. Care must be taken, however, that under no conditions can the direction of the lines generated by the solenoids oppose the lines existing in the magnetized needle, otherwise the value of the calibration is almost instantly destroyed.

For measurements of alternating current voltage, and also for the measurement of the watt output of any alternating current source of energy, the dynamometer system, in one of its many modifications, is unquestionably the best type of instrument that can be used. This instrument indicates directly the mean effective voltage of the line to which it is connected, and is equally accurate for direct current measurements, provided readings are taken with the direct current flowing through the instrument in one direction, then the direction of the current flow reversed and a second reading taken, the mean of the two readings being the correct value of the impressed electro-motive force. This for the reason that the instrument is extremely susceptible to the influence of external fields. Further, the dynamometer type of instrument is only properly adapted for use in portable instruments. The fact that two readings are necessary on direct current prohibits its use as a switchboard instrument on direct current circuits, and its delicacy, coupled with its field of low intensity and its sus-

ceptibility to error, due to the presence of iron in its immediate neighborhood, whether used on direct or alternating current circuits, renders it impracticable as a switchboard instrument for alternating current circuits. As an ammeter, it cannot be successfully employed for measurements above ·5 ampère, due to the difficulty of providing perfectly flexible contacts capable of carrying large currents. When you attempt to convey a current into a moving coil beyond the carrying capacity of a flexible conducting spring, recourse must be had to mercury contacts, and a mercury contact should never be employed in a portable or enclosed type instrument. In the dynamometer instrument great care must be taken to have the moving coil as light as possible; and to render the instrument aperiodic, or deadbeat, an aluminum air vane, moving in a partially enclosed chamber, must be employed. Manually operated brakes acting on the delicate moving system should be avoided, as their continued use results in a serious derangement of the moving parts.

Instruments based on the principle of the D'Arsonval galvanometer are very extensively used to-day for both switchboard and portable instruments on direct current circuits; they can be calibrated so as to show an equally divided scale, and, if properly constructed, are an extremely efficient instrument. Further, they are very well adapted to the measurement of resistances and grounds. In the construction of this type of instrument the important factor is the permanency of the permanent magnet fields employed. It is essential, in the first place, that the proper grade and quality of steel shall be employed, which means a steel possessing high permeability and a high degree of retentivity; then this steel must be carefully worked within definite limiting temperatures and must be treated with great care and skill in the processes of magnetizing and ageing. Further than this, the moving coil should be extremely light and the whole system carefully shielded from the influence of external fields, and yet so shielded that the moving coil will not be robbed of an appreciable number of lines of force, due to the presence

of the shielding iron. The greatest field for this type of instrument is in the measurement of heavy currents; that is, for currents of 1,000 ampères and upwards, due to the fact that it can be operated as a shunt instrument, requiring an extremely small drop of potential, full scale being obtained with a drop of from ·03 to ·05 volt. This means a relatively high efficiency, and, while the instrument does not possess all of the advantages of a series ammeter, yet it is far easier to install, and, where a high degree of accuracy in current indications is not demanded, will be found very satisfactory in practice.

Further than this, the D'Arsonval instrument, which gives deflections directly proportionate to the current flow, lends itself readily to a large variety of measurements, such as determining resistances and measuring the drop of potential from which resistances and grounds may be readily computed. It is, however, a type of instrument which should be handled with great care, as rough handling or the presence of powerful external fields will permanently destroy the accuracy of its indications. Further, since it depends primarily for its continued accuracy on the maintenance of a field of uniform strength, as supplied by its permanent magnet field, instruments of this type should be frequently checked to ascertain whether the permanent magnets have maintained their initial strength.

A great deal might be said on the subject of the last type under consideration, namely, the electro-magnetic system, for there are probably more variations in practical construction contained in this type than in all the other types put together; some are good, many very bad. It is, however, unfair to adopt the policy of certain engineers, who unqualifiedly condemn every electro-magnetic instrument, solely and entirely on the grounds that they contain a moving mass of iron, which, in their opinion, must render the instrument subject to errors of lag and hysteresis. My practical experience with this type of instrument, covering a great many years, has taught me that it is perfectly possible to so construct an electro-magnetic instrument containing a mass of moving iron that errors of lag and hysteresis,

if they are present, are so small as to be negligible. In order to achieve this result it is necessary, first, to proportion every part of the instrument with reference to all other parts; to carefully shield the instrument from the influence of external fields, and this by means of a shield that will not introduce errors due to its own retentivity. The iron employed should be very small and very light, and should be selected, after careful test, for purity and absence of retentivity. It should then be formed up with care, and so treated that oxidation is practically impossible. The field due to the actuating solenoid should likewise be carefully studied, and should be designed so that the moving iron will at no time be completely saturated, and yet of sufficient strength, in conjunction with the shield employed, as not to permit the indications of the instrument to be seriously influenced by external fields. In no case should two masses of iron be employed, as is common in some types of instruments, which depend on the repulsion of a moving vane by a fixed vane of similar polarity, both being energized by the actuating solenoid. It is almost impossible to free double vane instruments from errors of lag or hysteresis, and there is a further tendency for the pointer to stand off zero, due to the residual magnetism mutually induced in the two vanes.

The fact that the instruments constructed on the electromagnetic principle contain no material subject to change or deterioration, coupled with the fact that they can be built solidly and substantially, and controlled by gravity in place of a spring or springs, renders them exceedingly reliable in practice. If their calibration is correct when first installed, there is no reason why the calibration should change with time.

In the above brief description of the most common types of indicating instruments, it may be noted that there is no one type which is universal, that is adapted for both switchboard and portable use for either direct or alternating current measurements. While we can very readily dispense with the hot-wire and electro-static instruments, the other four types are essential for some class of measurement, and

for any particular line of measurement the most suitable system should be selected. It is possible that some day a universal system may be found, but, until that time, the user must select from existing types the one which in principle seems most applicable, not only to the character of electrical energy to be measured, but, also, to the conditions under which measurement must be made.

There is no one line connected with the electrical industry in which so much attention must be paid to details as in the manufacture of electrical indicating instruments. A very prominent engineer remarked to me recently that he had examined the construction and operation of a great many different types of indicating instruments, and, while a number of them bore evidence of similarity in design and construction, yet, in some cases, the manufacturer seemed to have acquired the "trick" of proportioning, manufacturing and calibrating, while others utterly lacked the "trick." As a matter of fact, it is not altogether a case of acquiring the proper "trick," but is a case of studying the theory and design of instruments for a number of years, backed by a large and varied experimental experience, which marks today the difference between the successful and unsuccessful instruments in the various types commercially exploited. Account must be taken of the most petty details of construction, the most careful and skilled labor must be employed in each department, and every particle of material entering into the instrument must be carefully selected and tested with reference to its particular function.

Personally, I have seen the experiment tried of taking a finished and efficient instrument and placing it in the hands of a careful and skilled mechanic for duplication; every wire and every part would be, apparently, an absolute copy of the original, and yet the results obtained would be totally different. It follows, therefore, that it is always wise in placing orders for electrical instruments to select a house who have publicly demonstrated the fact that they have learned the necessary "trick" or "tricks" of their profession.

In no line does reputation count for more than in the

manufacture of indicating instruments, nor is there any line in which I have been brought in contact where it takes so long a time to establish a reputation. Further than this, there is no line in which a greater amount of patience is required by the manufacturer. The average purchaser is totally ignorant of the laws or principles embodied in the instrument he is using, and, without regard to the fact that he may have selected the wrong type for the particular class of measurement he wishes to make, unhesitatingly blames the manufacturer for not having known what he wanted and for not having supplied him with the proper type of instrument by pure intuition.

Another obstacle which is commonly met by instrument manufacturers is the fact that for the average installation he is required to furnish instruments delivered to the switchboard contractor, who may or may not handle the instrument properly. It is true that most instruments are sealed, yet it is perfectly possible to utterly ruin the calibration of almost any type of instrument by improper handling without destroying the seal or opening the case. For instance, if a D'Arsonval instrument is laid upon the frame of an actively excited dynamo or motor, its entire calibration will be almost instantly changed, and yet no external evidence is presented to show exactly what has happened. Rough handling and an occasional fall, or improper packing for delivery to the plant, may further operate to destroy the accuracy of the calibrated instrument; yet the manufacturer is expected to provide instruments which will stand such usage and which, after they have been installed, may be subject to the influence of such strong external fields or such high external temperature as to make their correct indications impossible; and, after all of this, must have his instruments accepted or rejected by the consulting or supervising engineer, who, on the day of the test, carefully checks them with his personal portable instruments, which are usually kept in almost ideal condition and seldom or never leave his immediate possession. Some day I trust these conditions may be modified to the extent that the engineer in charge will test and check the instruments, if

he doubts the accuracy of the maker's calibration, before the instruments are shipped; or else issue instructions that the switchboard shall be drilled from template and the instruments set in place by the engineer's own assistants. In several cases I have succeeded in having the latter course adopted, with the result of mutual satisfaction on part of the owner, engineer and ourselves.

If arrangements could be made to have all instruments installed under the supervision of the engineer in charge, it would then be quite sufficient to have the specifications state the limit of error allowed in the indications of the voltmeters and ammeters; and this information, coupled with a specification covering the style of case, character of scale, range and class of measurement to be made, would enable the manufacturer to make an intelligent tender for the instruments required in any installation.

While a high degree of accuracy is desirable in all indicating instruments, it is particularly important that the voltmeter should be right within at least 1 per cent., since a variation of 1 per cent. in voltage means a corresponding variation in the candle-power of every incandescent lamp which may be in circuit. It is quite well known that the candle-power of any incandescent lamp varies directly with the voltage, the variation being approximately 1 candle-power for every volt increase or decrease from the normal voltage of the system.

Further than this, a variation of 1 per cent. from normal voltage on a system carrying incandescent lamps means a variation of about 16 per cent. in the life factor of the lamp and about 3 per cent. in the watt consumption per candle-power. Errors in the indications of ammeters do not produce such serious results, yet it is desirable that they should be accurate in order to obviate the danger of overload on circuit, translating device, or generator; and in the case of test instruments, as high a degree of accuracy should be demanded as is required in the voltmeter.

While on the subject of accuracy of indications, I would like to impress upon you the fact that, while we have three electrical units in common use, namely, the volt, ohm and

ampère, the ohm and ampère are the only two fundamental units, the volt being a derived unit. The absolute ohm may be quite readily obtained, and, as you probably know, is defined by law as the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14·4521 grams in mass, of a constant cross-sectional area, and of the length of 106·3 centimeters. The ampère is likewise defined by law as the practical equivalent of the unvarying current, which, when passed through a solution of nitrate of silver in water in accordance with standard specifications, deposits silver at the rate of ·001118 gram per second. The volt is defined as the electro-motive force necessary to send 1 ampère through 1 ohm. This, as you will note, gives us fundamental values for the ohm and ampère and defines the volt as a derived unit, and I am laying stress on the matter for the reason that the average electrical writer defines the volt as a fundamental unit equivalent to $\frac{1000}{1434}$ of the potential at the terminals of a standard Clark cell, and then defines the ampère as that current which 1 volt will cause to flow through a resistance of 1 ohm. As a matter of fact, the Clark cell is a secondary standard, exceedingly useful in practice, but not designed for use as a fundamental standard, due to the fact that Clark cells will vary among themselves and will give a gradually decreasing voltage at their terminals after they have been in service any length of time. It is, further, impossible to take 1 ampère from a single Clark cell without permanently ruining it; and, as a matter of fact, the potential of a Clark cell is only correct when the cell is used on open circuit.

It has been rather difficult for me to understand why the absolute ampère has been so little used or so seldom referred to, when it is a unit more readily verified than is possible with the volt. It is true that the fundamental method of determining the ampère is rather slow and tedious, but it is extremely easy to obtain the absolute ampère in c. g. s. units by the use of the tangent galvanometer. Defined in c. g. s. units, the ampère is such a current that, passed through a conducting wire bent into a circle of the

radius of 1 centimeter, will attract a unit magnetic pole held at its center with a force of one dyne; and this method applied to the tangent galvanometer gives the very simple formula of current equals galvanometer constant into the tangent of the angle of deflection of the polarized needle, the galvanometer constant being readily determined from its dimensions and the number of turns of wire, in connection with a determination of the value of the horizontal component of the earth's magnetism. Having once determined the absolute c. g. s. value of the ampère, we know that the practical ampère is $\frac{1}{10}$ the value of the c. g. s. unit. Having obtained the absolute standards of current, expressed in ampères, and resistance, expressed in ohms, the standard volt is readily determined from the relations given in Ohm's law. With the primary units once determined, all others, such as the farad or coulomb, can be readily obtained.

To obtain absolutely correct standards of voltage and current for alternating current calibration, it is only necessary to calibrate a dynamometer voltmeter and a dynamometer ammeter in true volts and ampères, as determined by fundamental standards; then, as a dynamometer measures directly the square root of the mean square, it will indicate correctly the virtual voltage or current in an alternating circuit. In calculating resistance in alternating current instruments, it is necessary to modify Ohm's law to the extent of substituting impedance for resistance. Since impedance is the vector sum of the ohmic and inductive resistances, it is readily obtained by triangulation when the two resistances are known, or when one is known and the angle of lag can be ascertained.

While the design, workmanship and material entering into the construction of an instrument are of vital and fundamental importance, the actual calibration is equally important. Assuming the manufacturer has reliable standards of voltage, current and resistance, trained observers are necessary who should be instructed not only to properly mark the scale, but to check it; and should also be instructed to carefully test the instrument for errors due to

reversal, to lag or hysteresis, and for errors introduced by the presence of external fields, or by the variations of internal or external temperature. Certain definite limits must be set for errors allowed, and no instrument permitted to go out until it has fully come up to the standard so set. In the company with which I am associated, we not only make all of these tests and check readings, but, likewise, provide an additional check on the calibration by plotting the calibration curve at the time the scale is made by the draughtsman, and if errors or irregularities are observed in the curve showing a departure from the standard curve applicable to the type of instrument under construction, the instrument is promptly returned to the calibrating room to have its readings checked, or to hunt for and remove the defect which caused the irregularity. It is a known fact that for every type of system there is a characteristic scale, following a more or less complex law, and any variation of the calibration from the normal indicates immediately that there is something wrong, either in the construction of the instrument or of some of the elements entering into it; or else it was inaccurately calibrated. I, personally, attribute a great deal of our commercial success to this intermediate checking in the drawing-room, and you can put it down as a settled fact that any manufacturer who produces instruments of any particular type the scales of which for corresponding ranges vary greatly from one another has not yet mastered the proper design or construction of his instrument.

It would be impossible to detail the many different kinds of measurements which can be made with the proper type of voltmeter, ammeter and wattmeter. In general, however, the possession of these three instruments enables one to measure not only voltage, current and power, but, likewise, capacity, inductance and resistance; and from these various measurements may be obtained data covering the performances of almost any type of generating or translating device.

There are many special forms of indicating instruments designed to indicate directly some of the various measure-

ments most frequently employed, two of which, at least, are so universally used at the present time that they deserve, at least, passing mention. One is a voltmeter designed for use on constant current arc light circuits, capable of indicating directly the total electro-motive force of the dynamo, and so connected by means of self-contained switches that not only can the total voltage of the dynamo or circuit be read, but, likewise, the presence of a ground indicated and its actual value in volts directly determined. This involves an arrangement of connections so that the voltmeter can be connected directly across the terminals of the circuit and then connected successively from the plus and minus side of line to ground. From the three readings thus obtained the number of lamps burning can be directly ascertained, the presence of the ground shown and the ground itself can be absolutely located by a very simple calculation. By employing, in addition to this, the known resistance of the instrument, the actual resistance of the ground in ohms may be obtained, thus defining its character.

An instrument of this character was brought out by my company some few years ago, and has met with almost universal favor, due largely to the growing tendency to measure resistances under full working potential. Such an instrument will show grounds which would not be shown by the ordinary galvanometer and bridge method of testing, and further enables the switchboard attendant to locate grounds while the line is in operative condition.

Another instrument which, for a time, fell into disuse, but which to-day is being used more extensively than ever, is the differential voltmeter, designed primarily to show the difference in potential between the bus bars and any dynamo which has to be connected to the bus bars in parallel with dynamos already operating. It is rather a curious fact that the average dynamo tender places implicit confidence in the indications of his differential voltmeter. The mere fact that he can see the pointer come back to zero when the free dynamo is being brought up to voltage, and the knowledge that when the pointer does stand at zero he

can throw the free dynamo into circuit without danger of trouble, impresses him with the idea that the instrument is essentially reliable and accurate, and he is ready to condemn any or all of his regular switchboard voltmeters which fail to agree with it in indication. This tendency has led my company to devote special attention to the calibration of differential voltmeters and to furnish them with a full scale which indicates the exact voltage of the bus bars, in place of furnishing instruments which give full scale deflections for 10 per cent. or 20 per cent. of the normal voltage.

In closing, I would say that I know of no subject connected with electrical engineering which promises such rich rewards for investigation as the subject of electrical measuring instruments, and if my hasty and very general review of the subject will influence any one to pursue the subject thoroughly and scientifically, I shall feel more than repaid. I have confined practically my entire time and attention to this line for a number of years and find the subject grows more interesting the further I investigate it, and I hope the time is not far distant when the literature on this subject will be as complete and as comprehensive as that now available in allied branches of electrical engineering.

THE FRANKLIN INSTITUTE.

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ELECTROMAGNETIC MECHANISM, WITH SPECIAL REFERENCE TO TELEGRAPHIC WORK.

By R. A. Fessenden.

(*Continued from vol. cxlix, p. 470.*)

Any motion which reduces the energy must have a force. Thus, since the energy would be reduced by enlarging the size of the plate of the condenser, keeping the charge constant, the plates of a condenser tend to stretch themselves out sideways if they are prevented from coming together. Thus we can make a nice little electrometer by taking a

piece of microscope glass, or a bit of a thin glass bubble, silvering one side of it and putting a drop of mercury on the other side, the glass being horizontal, with the silvered side down. A drop of mercurous chloride may be dropped on the mercury to take away its surface tension if it is desired to have great sensibility. Then if we put a refractometer over the mercury drop and connect one terminal of the cell whose voltage it is desired to measure, to the silver and the other to the mercury, we shall see the interference fringes move and can measure the voltage. If still greater sensibility be desired, we may put the unknown voltage in series with a known voltage of much higher value.

We may next consider the dielectric circuit *Fig. 1*, in

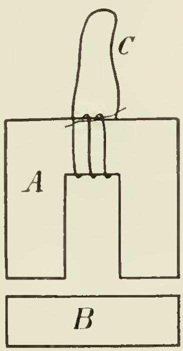

FIG. 1.

which we have a circuit consisting of the glass horseshoe *A*, and keeper *B*, these being in contact.

By winding turns of iron wire, *C*, around the glass horseshoe, and making the magnetic flux in the iron wire vary, we get a voltage round the glass circuit numerically equal to the time rate of change of magnetic lines passing through the central opening in the glass circuit. This voltage divides itself up inversely proportionally to the capacity ($\varkappa / 4 \pi \times$ area $\div$ length $=$ capacity) of the different parts of the circuit. If both keeper and horseshoe are of the same cross-section, the voltivity, F, will be equal to the total voltage, E, divided by the total length of the circuit. The total flux of electrostatic lines will be numerically equal to $E \times (\varkappa / 4 \pi \times \text{cross-section} / \text{length}) = Q$, or, $D = F K$.

In this case the electrostatic lines flow around the glass circuit, just as magnetic lines round an iron circuit. There is more leakage, however, in the case of the glass circuit than generally in the case of the iron, as κ for glass is only about three times what it is for air, and μ for soft iron may be 3,000 times μ for air. For highly saturated iron, however, the value of μ may fall to 2 or 3 and the distribution of the magnetic lines become exactly the same as that of the electrostatic lines.

Let us calculate the pull with which the glass keeper is attracted to the glass horseshoe. We will first calculate the energy in the circuit when the keeper is on.

If the circuit be of length L, area 1 square centimeter cross-section, capacity κ, and the time rate of change of the magnetic flux through the central opening is $d\,P\,/\,d\,t = E$, the total voltage round the glass circuit, then the drop of voltage per centimeter, or the voltivity F, equals $E\,/\,L$. The flux of electrostatic lines per square centimeter will be then $F\,\kappa = D$.

Since the energy per square cubic centimeter is $D^2\,/\,8\,\pi\,\kappa$, the total energy will be $L\,D^2\,/\,8\,\pi\,\kappa$ (the cross-section being 1 square centimeter, the volume is equal to the length $\times$ unity).

Next pull one side of the keeper away from the horseshoe so that there is a minute crack there, of length l. Then the energy will pile up in that crack and will flow away from the rest of the circuit, also the total amount of energy in the circuit will be lessened.

Now this is a case where, the voltage being kept constant, the dielectric is changed in configuration, and as we saw before, this means that the exciting circuit has a change of energy equal to double the change of energy stored up in the dielectric circuit, *i. e.*, equal to the sum of this change and of the mechanical work done. In this case the work done is negative, *i. e.*, work is spent in pulling the keeper, and consequently the energy in the dielectric circuit decreases by the same amount, whilst the change of flux in the dielectric circuit makes an increased gilbertance in the magnetic circuit linked with the horseshoe, and the mag-

netic flux jumps up as we pull the keeper away and tries to keep the electrostatic flux constant. Consequently both these quantities of energy go to the magnetic circuit, and since we have no true magnetic current (there may be such a thing, but the method of producing it has not yet been published), ultimately appears in the electric circuit which causes the change of flux in the magnetic circuit threading the horseshoe.

To calculate the amount of energy now resident in the circuit we see, since the electrostatic lines have been re duced owing to the increased reluctance of the circuit on account of the gap, from D to D_1, the energy in the glass is now $L\, D_1^2 / 8\, \pi\, \varkappa$ and that in the gap is $l\, D_1^2 / 8\, \pi\, \varkappa_1$ (since the same lines thread the air gap as thread the glass and the cross-sections are the same, the value of D_1 is the same for both air gap and glass).

We find the value of D_1 by considering that the total voltage, subtracted from that used up in the gap is the amount left for driving the electrostatic flux through the glass. So the new value of F is now $E - D_1\, l / L$ and

$$D_1 = \varkappa\, (E - D_1\, l / L)$$

The energy in the glass is now $D_1^2 / 8\, \pi\, \varkappa$ times the volume of glass and that in the gap is $D_1^2 / 8\, \pi\, \varkappa_1$. Adding these and subtracting the sum from $D^2 / 8\, \pi\, \varkappa$ (the original energy in the glass), we get, on simplifying the result:

Total change of energy is

$$D\, D_1 / 8\, \pi\, \varkappa_1$$

But when the crack is indefinitely small, D_1 varies infinitely little from D, and the formula becomes

$$D^2 / 8\, \pi\, \varkappa_1$$

When the substance in the gap is air, for which $\varkappa_1$ is unity, the formula becomes

$$D_1^2 / 8\, \pi$$

So much for the dielectric circuit. I have gone into it in some detail so as to show the general method of working and to obtain a certain depolarization of ideas in regard to

fluxes. To apply our equations to the magnetic circuit all we need to do is to change D to B, $\varkappa$ to μ, and F to H.

Take the case of a permeameter. Here instead of a glass horseshoe we have an iron one, instead of an iron wire carrying a varying magnetic flux we have a glass wire carrying a varying electrostatic flux, or more simply, a copper wire carrying a current. Just as the voltance in the glass circuit was given by the time rate of change of magnetic induction, so the gilbertance in the iron circuit is given by the time rate of change of electrostatic flux, or since unit quantity of electricity is, for our sins, defined as being the origin of 4π electrostatic lines, by $d / d t \, (4 \pi Q) = 4 \pi \times$ current, and the force required to pull the core in two is given by

$$B^2 / 8 \pi \mu_1$$

per square centimeter of cross-section of the core.

It will be noted that this formula is different from that given in books on the subject. This is because the formula generally given, *i. e.*, $(B^2 - H^2) / 8 \pi$, when the coil is not moved with the core, is incorrect. For it makes absolutely no difference as regards the force whether the coil is moved or remains at rest with respect to the pulled piece. It is unnecessary to enter into a discussion of the way in which this error arose, but we may easily show that the H^2 should not be in the formula.

For, consider the magnetic circuit when the core has been pulled apart a small distance, the coil remaining stationary. Fasten the coil to the moved part of the core and replace that part in its first position. If the usual formula be correct, more energy will be gained on the backward movement than was expended on the forward one. Now release the coil from the core and move it to its first position. Both theory and experiment agree as to the result, that no work will be done in making this last movement. Consequently, by repeating the operation we have a source of unlimited energy, or a perpetual-motion machine in the ordinary usage of that term.

The formula

$$\text{Average force} = B B^1 / 8 \pi \mu_1$$

when a portion of the circuit is moved to such a point that the original flux changes from B to B^1, the medium in the gap, being of permeability μ_1 will be found to be very generally useful in practice, where the amount of magnetic leakage does not vary during the motion to an appreciable extent compared with the amount of the main flux B.

Before leaving the subject it may be well to point out that pulling tests run a very great chance of being inaccurate through the change of induction as the crack begins to form. When one side lifts first the lines will move to the other side, thus increasing the value of B there, and as the total P remains the same as before, the average B^2 is much larger. To a certain extent this occurs of course and that it does not give quite large errors is possibly due to the fact that polished metal takes a skin, and that, as Ewing has shown, the two cut surfaces, no matter how well polished, always have a reluctance equivalent to an air gap of about ·003 centimeter in length. The presence of this initial virtual air gap renders the effect of slight tilting very much less than it would otherwise be; so also may the effect of self-induction, for this would oppose any sudden change in the position of the lines. The self-induction of the magnetizing coil also tends to keep the total amount of number of lines constant.

On the whole, however, the permeameter gives quite sufficiently exact results for most practical purposes, and all these different effects, as well as that due to the change of flux with change of mechanical stress on the core, seem to average up somewheres near the correct result. The following is a simple and correct formula for use with the permeameter:

$$B = \frac{4\sqrt{2F}}{d}$$

where d is the diameter of a circular rod and F the force in dynes.

For accurate work, however, I prefer the following device, *Fig. 2*, constructed three or four years ago, by Mr. Willyoung, to my designs, which enables induction and hysteresis

tests to be made of both bar and sheet iron with very considerable accuracy.

The bar, 1 centimeter in diameter, magnetized by the coil *K*, has a screw thread cut on each end, by a very correct die, and is screwed without twist in the blocks *A C*. There is thus very good magnetic contact all round and the actual reluctance is easily measured by turning the rod to different diameters or by using rods of two lengths. This latter method was first published by Ewing, some years ago, but this apparatus was then a year old.

A grid of wire *H*, hung in the slot *F*, has a current passed through it till it moves a certain amount, determined by

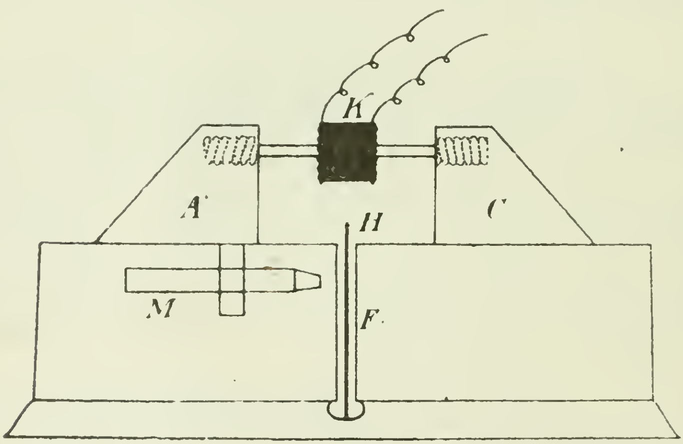

FIG. 2.

the microscope *M*, and the amount of current necessary to do this is inversely proportional to the flux. It works very well when the grid is properly wound, but for some reasons it is more convenient to wind a few wires on a frame and drop them through the slot, observing the effect on a ballistic galvanometer.

Sheets of iron are cut to size and their ends interleaved in a pair of pieces similar in size to those used for the solid bars. One advantage of this method is that if any error is taken in a reading it can be repeated, and, in fact, it seems remarkably well adapted to the work.

A peculiar case is that shown in *Fig. 3*, where one pole piece is of greater area than the other, one being, say, 1 square centimeter and the other 4 square centimeters. According to theory, the pressure on the one face should be, if the total number of lines is P, $P^2 / 8 \pi \mu$ and that on the other, $4 (P / 4)^2$, one being thus four times as great as the other. For a time I felt rather disgusted with the perpetual-motion men, that they had not hit upon the simple device of fixing such a magnet on an axis passing through its plane and driving unlimited machinery with it, the acknowledged and patent presence of the magnet rendering the detection of extraneous electric power rather difficult, until I remembered Stevenson's fisherman—"It is in my

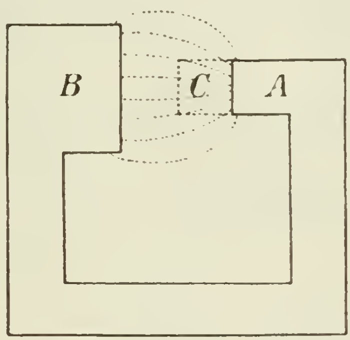

FIG. 3.

thought that one thing is as good as another," and reflected that perhaps they were wiser in their generation and were more concerned about finding the dupes than the means for duping.

The explanation, of course, is that when you move the pole A up to a short distance towards the pole B, you do not cut out a slice of magnetically stressed space C, but really change the whole configuration. Now, it will be seen that, in addition to changing the flux in space C from that which was originally in the air and ether to that which is now in the ether and iron, we have also moved together all the lines. Thus work has been done against their mutual repulsion. So that the real force is got by taking the energy

gained and dividing by the distance. It is evident that the change of configuration will be the same whether it is A or B that is moved, provided they are moved the same distance, and, the change of work being measured by the initial and final states being thus the same, for a given movement, the force will be the same.

How about the $B^2 / 8\pi$ forces then? Well, I have not calculated out the direction of the lines for any particular case, in fact it is practically impossible to do so, for though the methods of conjugate functions which have been applied by Maxwell, Kirchoff and others give us the solution of some simple case in two dimensions, yet they are not applicable to such cases as this, where the permeability changes with the induction and the dimensions of the faces are of the same order as their distance apart.* But it is fairly easy to see that what happens is that the lines bow themselves out from the smaller cross-section, as shown in the figure, and leak out at the sides so as to make the integral of the normal component over A equal to the integral of the normal component over B. This fact can be made use of to calculate the direction in which the lines leave the face.

Thus the pull between two such surfaces, since the lines cannot leave B at exactly right angles to its surface owing to their mutual repulsion, must be very slightly less than the value of $B^2 / 8\pi$ at the surface of B, multiplied by the area of B.

A simple way of seeing this is to let both poles be the same size at first. Separate them a certain distance and then let one contract in cross-section. The work done in contracting gives a force at right angles to the line of joining the faces, and so does not affect the pull. Similarly, when, as in an air gap, the flux passes from a substance of one permeability to one of a different permeability, the purely magnetic forces on the two sides cannot be equal. It is

* The method which has been suggested, and even employed, of drawing straight lines from one surface to another, deducing the flux from them, leads, of course, to absurd results.

usual in electrostatics to attribute such effects to fictive layers of electricity, in the attempt to make the electrical forces balance each other across an interface. This artifice is without physical justification, as Heavyside has shown ("Electrical Papers," Vol. I, p. 247). My own theory (hypothesis) is that the balancing is done by purely mechanical forces, *i. e.*, that in a permanent magnet, for example, the ends of the air gap, when the keeper is off, pull the two ends of the magnet together, the molecular force balancing the difference in the magnetic forces. Generally speaking, it is surprising how little we know about the workings of a permanent magnet, and the subject is well worthy of investigation. Some things, however, we can see at once. For example, that the flux in a permanent magnet is greater when the keeper is on than when it is off.

TYPES OF ELECTROMAGNETIC MECHANISMS.

Taking the formula

$$\frac{Q\,P}{\kappa^{\frac{1}{2}}\;\mu^{\frac{1}{2}}} = \frac{M\,L_x\,L_y\,L_z}{T^2}$$

and substituting for $\kappa^{\frac{1}{2}}\;\mu^{\frac{1}{2}}$ its value,

$$\frac{T}{L_z}$$

we get

$$\frac{Q\,P}{T} = \frac{M\,L_x\,L_y}{T^2}$$

The energy stored up in the magnetic field due to the strain is given in various forms, for instance, as $\frac{1}{2}$ L I^2, where L is the coëfficient of self-induction, and as

$$\frac{H\,B}{8\pi} \times \text{volume}$$

These are equivalent, as may be seen by taking the case of a closed ring.

For L I is the total number of linkages
= lines $\times$ turns = B $\times$ cross-section $\times$ turns.
since B $\times$ area = total number of lines.)

$$I = \frac{\text{gilbertance}}{4\pi \times \text{turns}} = \frac{H}{4\pi} \times \frac{\text{length}}{\text{turns}}$$

since the total gilbertance divided by the length of the magnetic circuit equals H.

$$\frac{1}{2} \text{L} I^2 = \frac{B}{2} \times \text{cross-sect.} \times \text{turns} \times \frac{H \times \text{length}}{4\pi \times \text{turns}}$$
$$= \frac{H B}{8\pi}$$

In the case of a very long solenoid, also, the same is easily proven if we remember that the gilbertivity outside the solenoid is negligibly small.

We may pass a current about a magnetic circuit so as to obtain one of three results:

(1) Expend electrical energy equal in amount to $\frac{1}{2}$ L I^2, this being stored up in the dielectric and lost when the circuit is broken, being converted into heat.

(2) Expend electrical energy equal in amount to L I^2, one-half of this, $\frac{1}{2}$ L I^2, being stored up and lost as before, the remainder, $\frac{1}{2}$ L I^2, appearing in the form of mechanical energy which can be utilized.

(3) Expend electrical energy equal in amount to 2 L I^2, all of which appears as mechanical energy and can be utilized.

The efficiency of the first method is zero, of the second, 50 per cent., and of the last, 100 per cent.

Practically all electromagnetic mechanisms, with the exception of electric motors, belong to a combination of the first and second classes.

Case I.—In Case I we complete the magnetic circuit first, and then produce a magnetic flux in it by passing a current around it. The linkages at any moment being L I, the back voltage, which is numerically equal to the time rate of change of linkages, is

$$\frac{d}{d\,t} \text{L}\, I$$

and the power

$$\frac{d\,W}{d\,t}$$

is at any instant

$$I \frac{d}{d t}\left(\mathrm{L} I\right) \quad .$$

Therefore,

$$W = \frac{1}{2} \mathrm{L} I^2$$

This is the energy needed to push the electricity along the wire against the back voltage. As nothing material moves, we get no mechanical work (if we neglect the slight expansion or contraction of the iron itself). When the current is stopped, the energy returns to the circuit; or, if the circuit is broken, it appears in the form of heat, in the spark or in the wires, due to oscillatory currents set up in them. I have said that this energy may come back to the circuit. This is not strictly true, for magnetic storage of energy is very inefficient. It is for this reason, as I have shown,* that single-phase currents cannot be efficiently split into two-phase by using capacity and self-induction. The energy stored in a closed magnetic circuit, as mentioned before, is

$$\frac{H\, B}{8\, \pi}$$

per cubic centimeter. But, as we shall see later,

$$H = \frac{\alpha\, \beta}{(1 - \beta\, B)}$$

where α and β are constants. So the energy per cubic centimeter is

$$\frac{\alpha\, B^2}{8\, \pi\, (1 - \beta\, B)}$$

The loss in hysteresis, per cycle, is by Steinmitz's law, for a fair brand of iron, for which $\alpha = {\cdot}0003$ and $\beta = {\cdot}00006$.

$$\eta = {\cdot}003$$

The efficiency is

$$\left\{ \frac{\alpha\, B^2}{8\, \pi\, (1 - \beta\, B)} - \eta\, B^{1{\cdot}6} \right\} \div \frac{\alpha\, B^2}{8\, \pi\, (1 - \beta\, B)}$$

Elect. World, August 29, 1895.

If $B = 10{,}000$, this reduces to

$$\frac{185}{375}$$

or not quite 50 per cent.

It is for this reason, as I have shown elsewhere,* that the presence of iron in a transformer cannot distort the curve of voltage, and that the curves of impressed back and secondary voltage cannot differ from each other by more than 1 per cent., and that the current curve also cannot be distorted except at loads of less than $\frac{1}{20}$ of full load, as otherwise, since distortion in such a case would mean a storing up of energy during a part of the period and the giving of it out again later, if distortion occurred to an extent greater than 1 per cent., the transformer would be so inefficient that it could not be sold. Hence the very common jibes about ironless transformer mathematics are senseless, and can only be made by those who have had no practical experience in electrical design.

Case II.—In this case the magnetic circuit is at first open, and supposed of infinite reluctance. The electric circuit being closed and the current flowing, the magnetic circuit tends to close itself, for the potential of a coil carrying a current is given by the formula

$$P\, n\, I$$

where P is the total magnetic flux, I the current in the coil and n the turns. This potential is negative when the lines are passing through the coil in the direction in which the current in the coil would tend to make them itself, and so, as the potential has its lowest (its greatest negative) value when the coil is enclosing as many as possible of the lines it produces, the circuit tends to move in such a way as to enable more lines to be made. At the end of the motion, when the armature has come to rest, the energy in the dimagnetic is as before,

$$\frac{1}{2}\, L\, I^2.$$

* *Ibid.*

But, as the armature moved, more and more lines were formed inside the coil, and these made a back voltage tending to choke back the current. The power which the electric circuit must furnish to keep on driving the electricity through the coil against the back voltage is calculated as follows:

The back voltage is, as before, the time rate of cutting of linkages, *i. e.*,

$$\frac{d}{d\,t}\,\mathrm{L}\,I.$$

But it is now L which is the variable, for the current was established before there were practically any lines threading the circuit. The power is, as before,

$$\frac{d\,W}{d\,t} = I\,\frac{d}{d\,t}\,\mathrm{L}\,I, \text{ whence}$$

$$d\,W = I^2\,d\,t \text{ and}$$

$$W = \mathrm{L}\,I^2$$

Half of this is spent in storing up the energy

$$\frac{1}{2}\,\mathrm{L}\,I^2,$$

which is equal in this case (since $P\,n = \mathrm{L}\,I$, all of P being due to the current in the circuit we are considering; if it were not, $P\,n$ would not equal $\mathrm{L}\,I$, as P is the *total* flux, no matter how derived, whilst $\mathrm{L}\,I$ is the flux due to the current I) to

$$\frac{1}{2}\,P\,n\,I,$$

in the magnetic circuit. This is wasted when the current is broken, appearing as heat. The rest,

$$\frac{1}{2}\,\mathrm{L}\,I^2 \text{ or } \frac{1}{2}\,P\,n\,I,$$

is available for mechanical work, and if not so spent, turns to heat, through the armature hitting against a stop, or, by oscillating back and forth, wastes this energy in heat through friction.

This method of getting work from electric energy is that usually used in electromagnetic devices. Though it may, theoretically, have an efficiency of as nearly 50 per cent., yet, as will be seen later, it is generally arranged so as to give but 5 per cent. to 20 per cent.

Case III.—In this method the magnetic circuit is not only closed, but has the flux passing through it before the actuating current is passed through the moving coil. The magnetic circuit may consist of either a permanent magnet or an electromagnet and an armature, both being fixed in position, and there being at least one air gap.

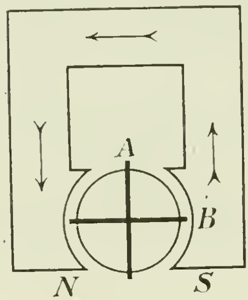

FIG. 4.

Fig. 4 shows such a device, where the coil A can rotate about an axis perpendicular to the plane of the paper. Taking the permanent flux P as passing in the direction of the arrow, from S to N in the iron, then if the coil be in position A, and has a current I in it, passing from back to front in the top of the coil, then the potential of the coil is $P\,n\,I$. It will then tend to move till it is horizontal to the position B, when it will enclose no lines and its potential will be zero. But by moving through a further angle of

$$\frac{\pi}{2}$$

or 90°, it can enclose P lines in the plus direction, its potential therefore becoming $-P\,n\,I$. It accordingly assumes this position and does $P\,n\,I$ more work, or $2\,P\,n\,I$ in all.

This work is done by the electric circuit, for the wire, in moving, has a voltage generated in it at any time equal

$$2 \frac{d}{d\,t} P\,n$$

and this, multiplied by the current I, which we maintain constant, gives us

$$2\,I\,n\,d\,P,$$

whence, in one-half revolution

$$W = 2\,I\,P\,n.$$

This all appears as mechanical work, for if the number of ampère turns on the coil is small compared with the gilbertance which drives the flux P through the circuit, P is practically constant. Suppose, however, that the current in the coil produces a flux P', then at first the potential is

$$(P - P')\,n\,I$$

when the current is made, and

$$\frac{1}{2}\,P'\,n\,I$$

work is done in making it. This work is furnished by the electric circuit A. During the first 90° of rotation work

$$(P - \frac{1}{2}\,')\,P\,I\,n$$

is done approximately, and during the next quadrant,

$$(P + \frac{1}{2}\,P')\,I\,n,$$

the total being $2\,P\,I\,n$. The energy

$$\frac{1}{2}\,P'n\,I$$

which was originally spent in starting the field is lost, appearing as heat when the circuit A is broken, and if P' is small compared with P, then, as mentioned above, the loss is negligible and the efficiency is practically 100 per cent.

These three cases may be illustrated by a simple mechanical analogue. Take a spring with a pan at its lower end as

in *Fig. 5*. Pour gradually 10 grams of sand into the pan, so that the lip of the vessel from which the sand is poured is always just touching the pan. The pan will, in descending, stretch the spring to a length of say 20 centimeters, and as the average weight in the pan was 5 grams, the total work done is 100 gram centimeters. Now tilt the pan and let the sand fall out, when the energy will be spent as heat, through the oscillatory motion of the spring. We have thus spent 100 grams of work and got nothing for it. This is the analogue to the first case.

Next add the 10 grams all at once. The pan will immediately descend with considerable velocity, and if we fix a wheel and pulley to it, we can get 100 grams mechanical work, as 10 grams moving through 20 centimeters

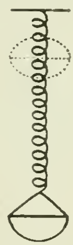

FIG. 5.

gives 200 gram centimeters of work, and there is only 100 stored up in the spring. If we now tilt out the sand, we only lose 100 gram centimeters, and our efficiency is 50 per cent. This is the analogue of the second case.

Now gradually pour, as in the first case, 10 grams into the pan. The spring is extended and comes to rest. This represents the formation of the permanent magnetic field in the third case. Then take 1 gram and drop it from the original position of the pan. When it reaches the pan it will have done 10 units of work, all of which we can get out in the shape of mechanical work, by letting it come down slowly. After it has reached the pan, the spring lengthens 2 centimeters more, doing 22 centimeter grams of work, of which, when the 1 gram is tilted out at the bottom, 2 gram centimeters is wasted. We have thus done 22

centimeter grams of work and utilized 20 of them. The efficiency is thus nearly 100 per cent. This is the analogue to the third case.

In each of the above cases, the circuit has been supposed to be broken when the movement was ended. What would happen if, instead of breaking the circuit, the voltage, and hence the current, were made periodic, and alternating?

In Case I, the energy would, to the extent of 50 or 75 per cent., come back to the circuit and be saved.

In Case II, the energy would come back to the electric circuit, but would not be available, except a fraction of it, as it would come back as a lot of higher harmonies of no particular use, and would fritter itself away in heating up the wire.

In Case III, after the current has once been started, *i. e.*, after several periods, the energy may be made to come back entirely, so that none of it is wasted. To accomplish this, however, the wire must move synchronously with the generator and the shape of its curve of back voltage must be identical in form with the voltage curve of the generator.

It will be noted that we have altogether neglected to take into account the $I^2 R$ loss of the magnetizing coil. This will be dealt with later, as it is entirely independent of the

$\frac{1}{2} \mathrm{L}\, I^2$ loss.

MOST EFFICIENT DESIGN.

As Case I is only of importance in certain instances which will be taken up later, we will deal with mechanisms of Class II first.

In these the current is flowing before the magnetic circuit is closed. As mentioned before, the energy obtained mechanically is only half that expended during the closing of the magnetic circuit.

But in most cases still more energy is wasted in that L is not zero at the instant that the armature commences its movement, and the mechanism is thus a combination of Classes I and II. Consider, for instance, a core in a solenoid.

Before the current is made, the coil has already an appreciable self-inductivity, and when the current is flowing at its final value we may suppose that the coil of 200 turns and 1 ampère makes a flux of 20,000 lines in the circuit. The linkages then are 20,000 $\times$ 200, and the value of L is then (20,000 $\times$ 200) $\div$ (1 / 10) (1 ampère being 1 / 10 absolute unit of current). The value of

$$\frac{1}{2} L I^2$$

is then 400,000 ergs, and, as we have seen, this amount of energy is wasted entirely. Suppose, then, that the plunger moves, till at the end of its stroke there are now 40,000 lines threading the circuit. The value of the coëfficient of self-induction is now (400,000 $\times$ 200) $\div$ 1 / 10, and there are now 400,000 more ergs stored up in the circuit. But this increase has been made by varying L, not I, and falls under Class II, so that an amount of energy equal to this must have been available for mechanical work, *i. e.*, 400,000 ergs. Thus, when we made the current we expended 400,000 ergs, and whilst the core was moving we expended 800,000 more, of which only half was available for mechanical work. Our efficiency is, therefore, 33⅓ per cent. instead of 50 per cent., as it would have been if the core had been out of the way entirely at first.

Our first rule, therefore, is as follows:

Rule I. In mechanisms in which the actuating current produces the magnetic flux, the magnetic flux before the armature has commenced its motion should be as nearly zero as possible.

[*To be continued.*]

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THE FELLOWS MACHINE AND CUTTER FOR GENERATING GEAR-TEETH.

[*Being the Report of the Franklin Institute, through its Committee on Science and the Arts, investigating the invention of E. R. Fellows. Sub-Committee.—Wilfred Lewis, Tinius Olsen, Arthur M. Greene, Jr.*]

HALL OF THE FRANKLIN INSTITUTE,
[No. 2025.] PHILADELPHIA, March 1, 1899.

The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the merits of Fellows' Machine and Cutter for Generating Gear Teeth, reports as follows:

The Fellows gear-shaper is a machine designed to generate a complete set of interchangeable gears from a single cutter, which is in form similar to one of the gears produced. It consists essentially of a frame or housing adapted to carry the gear blank and the cutter slide in proper relation to each other and connecting mechanism whereby the gear blank and the cutter are caused to roll together on

their pitch lines while the latter reciprocates like a shaping tool and cuts away the material presented to it in the wheel blank.

The gear-shaping machine is the subject of U. S. patent, No. 579,708, dated March 30, 1897, and the cutter and cutter-head thereof are covered by another patent of even date, No. 579,570. As shown and described in the former patent, the gear-shaper differs somewhat in its details of construction from the latest designs, an example of which was examined by the chairman of this sub-committee at the works of W. D. Forbes & Co., Hoboken, N. J., and in its present approved form an idea of the machine can be had from the illustrations shown in the *American Machinist* for December 7, 1897, and in the *Iron Age* for June 2, 1898, as well as from photographs accompanying the inventor's application and engravings published herewith.

The most novel feature of the machine, and that upon which its successful operation chiefly depends, is the cutter. This is essentially one of the gears in the set to be cut, modified as required to adapt it for use as a cutter. These modifications include a certain lengthening of the addendum to provide root clearanee in the wheel cut, top rake on the cutter faces and clearance angles on the cutter sides to facilitate the cutting process. Provision is also made for the continued use of the cutter by grinding, after it has become dull in service. It will readily be seen that a cutter thus formed and mounted can be made to produce tooth forms in a wheel blank rolled against it, which will engage the cutter pinion in proper rolling contact, and it may follow as a consequence that wheels which roll properly with the same pinion on the same pitch line will roll properly together. This general proposition must, however, be guarded by two considerations; first, the form of the cutting tooth must be a true odontic, capable of generating a rack with equal congruent branches, and, further, the shaping edge of the cutter must be sufficiently extended to form the actual working face on all the engaging wheels. The principle that one tooth form can be described from another in a mating wheel has been known for half a century at least,

and the process is clearly described in Willis' "Principles of Mechanism," edition of 1850; but it was not until November 16, 1881, that a practical suggestion of the application of this principle in a machine for cutting gear teeth was made. At that time Mr. Hugo Bilgram read a paper before the Franklin Institute entitled "A New Odontograph," in which he suggested for the first time the employment of a rack cutter in a shaping machine for the production of gear teeth in a wheel blank rolled against it.

Previous to this, in 1856, a somewhat similar idea had been advanced in England for the use of a hob in cutting spur gears, but the practical difficulties encountered must have discouraged the pioneers in this field, for, since then, the original idea of a machine for this purpose has been pursued with so little diligence as to have been repeatedly re-invented and re-patented in this country and abroad, and the process still seems to languish without evidence of commercial success. The hob generator differs, however, from the suggestion of Mr. Bilgram, in requiring the use of an expensive cutter with many teeth difficult to maintain in proper shape and working condition, whereas the Bilgram machine contemplated a cutter of the simplest form most easily reproduced. Notwithstanding the fact that the possibility of a practical machine for generating spur gears by means of a rack cutter was thus set forth about eighteen years ago, very little progress in this field appears to have been made since 1885, when a machine of this character was developed and patented by Ambrose Swasey. Here the cutters and gear blank moved together tangentially, and the effect of a continuous rack was obtained by shifting the cutters back to their original position during their return movement. A continuous cutting action was thus obtained, but at some disadvantage in effective construction. Mr. Fellows has extended the idea of a rack cutter to embrace a pinion cutter, thereby permitting a continuous rolling action between the cutter and the gear blank, and the use of the same cutting teeth repeatedly in the production of a gear wheel. The pinion cutter is also applicable to internal gears which are obviously beyond the scope of a rack cut-

ter, and, as an original conception of a practical machine having a large range of usefulness, the Fellows gear-shaper is clearly an invention of unusual promise; but a closer study of the cutter and the machine in general should be made before a definite conclusion upon their merits and possible defects can be reached.

The cutters presented for consideration are of two kinds, one of which appears in patent No. 579,708, as used on the machine there described in a position inclined to the face of the blank for giving the necessary clearance. As the cutter bar advances upon the wheel blank the slide upon which it is carried is made to recede a proportionate amount so that the resultant movement of the cutting edges is vertical. Here the cutting teeth are formed upon a cylinder, and may be ground after hardening to perfect involute form, and the cutting edges may be renewed, as required, by grinding their end faces without causing any change in their form or pitch diameter. The inclination of the cutter is so slight that its effect in distorting the effective shape of the cutting edges may be neglected as inappreciable, and in this form it is believed that the theoretical requirements for a renewable cutter have been practically solved. But the compound movement of the slide and saddle introduces more wearing surfaces to be maintained and more sliding joints to contribute their share of imperfection in the work, and in actual practice this feature has been abandoned in favor of a cutter with ground clearances mounted in a saddle which remains fixed after the proper depth of cut has been attained.

This cutter is described in patent No. 579,570, as "formed as a bevel-gear," the necessary side clearance being obtained by backing off about half a degree on a side. This method of obtaining clearance in the cutter implies a change of shape as the cutting edge is renewed by grinding, and this could not be accepted as meeting theoretical or perhaps even practical requirements, but from the method of grinding the cutters to proper shape, as illustrated and described in the *American Machinist*, referred to, it is believed that the sides of the teeth in the cutter

are really right and left hand spirals of very long pitch, and that they cannot properly be considered as resembling bevel-gear teeth at all. This view of the matter leaves nothing but clearances to be affected by sharpening, and grinding on the face of the cutter can evidently proceed without detriment to the wheels produced until the clearances originally provided are exhausted. The cutter, as thus made, cannot maintain, after grinding, absolutely the same tooth profiles as the cutter first mentioned and described in the patent, but the tooth forms are nevertheless just as true, and differ only in the non-essential element of clearance. Having thus provided clearance on the cutter teeth, it became possible to dispense with the compound slide originally intended for the same purpose, and a decided improvement in the actuating mechanism was thus brought about, giving the whole machine the appearance of greater simplicity, durability and effectiveness in its operation. This cutter combines the advantages of being ground easily and truly to perfect form, after hardening, by special mechanism used in its manufacture, and of afterwards being sharpened by grinding on its face only in an ordinary lathe, and these practical considerations cannot fail to win for it general favor, which it well deserves.

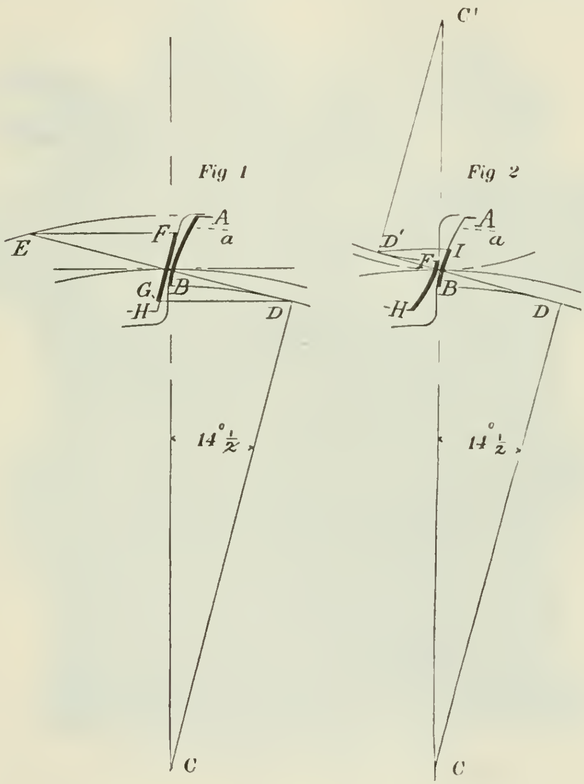
But, before stamping it with the seal of unqualified approval, some examination should be made with reference to its scope and limitations. The principles used in its construction may certainly be applied to an involute cutter having any number of teeth and any degree of obliquity, but attention should first be directed to the cutters actually made and put upon the market. These have twenty-four teeth and they are understood to be made for the production of involute gears in accordance with the Brown and Sharpe standard, $14\frac{1}{2}°$ obliquity. Here the addendum is ·3183 pitch, and the question arises whether this cutter of twenty-four teeth and $14\frac{1}{2}°$ obliquity will produce in the Fellows gear-shaper a perfect system of interchangeable gears from a twelve-toothed pinion to a rack; or, only a set of gears approximately correct, which may be run together without practical difficulty. It might at first be supposed that a

cutter generated from a rack by grinding would reproduce the same rack as a rolling cutter, but this does not necessarily follow, as will appear by reference to *Fig. 1*. Here the involute face of the cutter is shown by a heavy curved line *B A*, from the base circle *B D* to the addendum circle *A E*. That portion of the face between the base and root circles may be a straight line terminating in a fillet, or it may be undercut by the corner of the grinding wheel, depending upon how far the rolling of the cutter is continued while grinding; but it does not constitute a part of the true cutting edge of the cutter, and can only be regarded as an undeveloped or clearance edge on the cutter. The involute edge of the cutter acts along the line of action, *D E*, and generates within this line, the face, *G F*, on the rack. Between *F* and the root line there will be a clearance curve, and between *G* and *H* the point of the rack tooth will be more or less rounded. If the undeveloped edge of the cutter be left radial, the end of the rack tooth *G H* will be cycloidal in form, but if this edge be undercut, an important part of the face, *B A*, near the base circle, will be cut away, reducing the length of the true path of contact. It is not, therefore, possible to reproduce a perfect rack by means of the cutter in question, although it can be itself produced by a rack with equal congruent branches, but it is not denied that the differences pointed out cannot easily be observed in practice. As the number of teeth in the wheel cut is reduced, the rounded end, *G H*, grows shorter and finally disappears in wheels of thirty-five teeth and under. But another difficulty soon begins to appear in cutting pinions, and this will be understood by reference to *Fig. 2*. The end of the cutter, *I A*, which, on wheels of thirty-two teeth and over, forms part of the working face, now becomes engaged in cutting clearance below the base circle, and in the case of a twelve-toothed pinion, as shown in *Fig. 2*, the path of contact and the true working faces are very much reduced. The end *A* of the cutter also cuts away part of the face *F H* previously formed near the pitch line, and still further reduces the path of contact.

The larger the number of teeth in the cutter, the greater

will be the clearance swept out by the point A, and some interference might therefore be anticipated between pinions and large gears; but this danger of insufficient clearance is avoided almost perfectly by the extra addendum on the cutter, which provides root clearance at the same time.

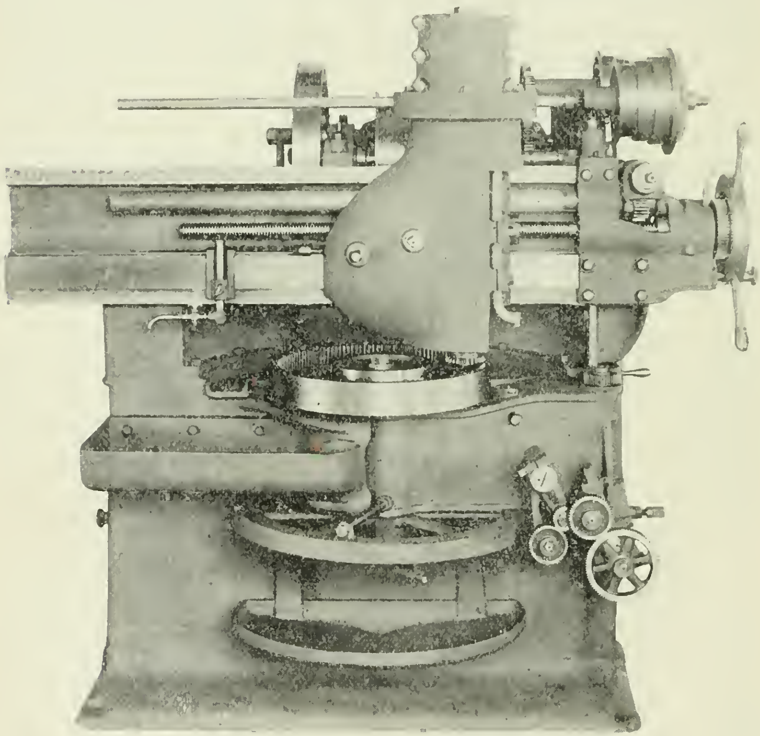
The commercial cutter submitted for examination thus appears to have some slight theoretical defects, but these



defects are inherent in the system to which the adaptation of the cutter is made, and not chargeable directly against the cutter itself, which will undoubtedly cut the teeth, for which it is intended, far better than they can possibly be cut by any set of equidistant cutters in the ordinary way.

The obliquity of the system is clearly at fault, and the

cutter adapts itself as well as possible to the difficulties presented, but as the obliquity is somewhat increased, the defects here noticed rapidly disappear, and the scope of the Fellows gear-shaper as a tool for the perfect formation of interchangeable gears becomes rapidly enlarged. The capabilities of the machine are broad enough to overcome all difficulties, and although cutters can easily be made of any desired obliquity, it has been thought advisable to

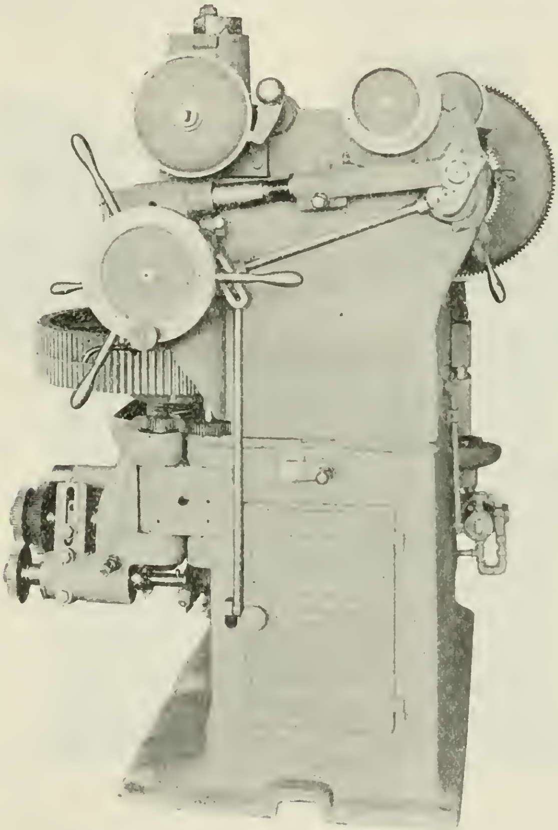


Fellows gear-shaper cutting external gear.

examine critically the cutters now on the market, and ascertain, if possible, the approach to perfection actually obtained in their use.

In the design of the machine throughout great ingenuity has been displayed and close attention has evidently been paid to every detail of construction, reflecting great credit upon the inventor. The cutter is perfectly made

to act on its rising stroke, pressing the blank against a stop on the head itself, thus minimizing the spring in the framework. On the return stroke the wheel blank is drawn away from the cutter to give the necessary clearance, and upon the completion of a wheel the feed is automatically disengaged and a bell sounded to notify the

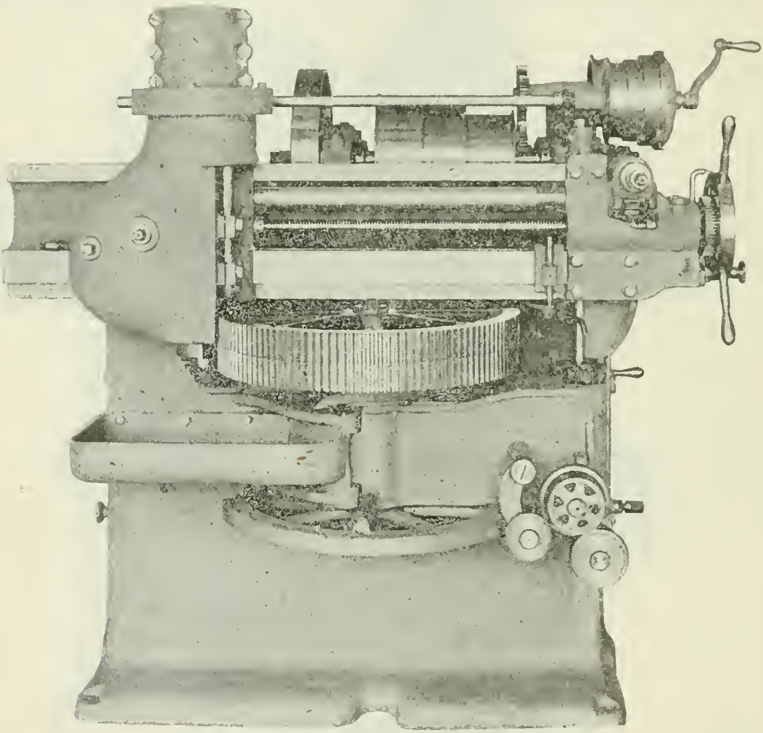


Fellows gear-shaper showing feed motion.

operator, who then removes the finished wheel and places another in position. When properly adjusted, the cutter feeds in automatically to the required depth, where it stops, and the wheel blank and cutter then begin to rotate together.

Although the driving mechanism was not particularly

powerful on the machine inspected and the feeds used seemed rather light, yet results were said to be produced with surprising rapidity, and to the perfect satisfaction of the owner of the machine. The witness, unfortunately, called at a time when the machine was not in operation, but from notes taken on the feeds and speeds in common use, the capacity of the machine was estimated at not less than



Front elevation of gear-shaper.

50 per cent. greater than common practice on gear-cutters in which a milling-cutter is used.

In view of the published articles on file with this application, it is not deemed necessary to encumber this report with further details of construction and operation. Suffice it to say that in design, general appearance and workmanship and in conveniences for adjustment and examination of parts, the Fellows gear-shaper is a very commendable

machine, on which there is little to be said by way of adverse criticism.

Possibly weak points will develop in time, for which the inventor will doubtless find proper remedies. At present, the speed of the machine seems to be limited by the cam mechanism, which moves the blank away from the cutter on the return stroke. This mechanism pounds heavily at moderate speeds, and might well be made the subject of further consideration on this account.

It may also be questioned whether a shaping tool can be pushed as hard as a milling cutter where rapid output is important on account of the well-known difficulty of preserving the edge of the work at the termination of a heavy cut in a shaping machine. On this account, a fine feed seems essential, and rapidity of production seems to be chiefly a matter of cutting speed.

The machine, as it stands, is, however, a well-developed tool, particularly applicable to the production of interchangeable gears, and the cutter used is more accurate in form, more easily renewed and covers a broader range of usefulness than the milling-cutters with which it competes.

Your committee believes that the machine and cutter for generating gear teeth, invented by E. R. Fellows, mark a distinct advance in the art of gear cutting, which should be recognized; and the Franklin Institute therefore recommends the award of the John Scott Legacy Premium and Medal to Edwin R. Fellows, of Springfield, Vt., for his "Machine and Cutter for Generating Gear Teeth."

Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, April 5, 1899.

JOHN BIRKINBINE, *President.*
WM. H. WAHL, *Secretary.*

Countersigned by
EDGAR MARBURG,
Chairman Committee on Science and the Arts.

THE LEVY ACID-BLAST METHOD OF ETCHING METAL PLATES.

[*Being the report of the Franklin Institute, through its Committee on Science and the Arts, on the invention of Louis E. Levy. Sub-Committee.—F. E. Ives, Chairman; Samuel Sartain, W. N. Jennings, Geo. H. Buchanan, F. E. Manning.*]

HALL OF THE FRANKLIN INSTITUTE,

[No. 2061.] PHILADELPHIA, May 3, 1899.

The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the merits of Levy's Acid-Blast Method of Etching Metal Plates, reports as follows:

Letters-patent for this invention were applied for under date of November 4, 1897, and granted on October 12, 1898. A second patent was applied for in September, 1898, and has since been granted.

Your committee examined the machine which was exhibited in operation and described by the inventor at the stated meeting of the Institute on February 15th, and which was found in practical operation at No. 628 Chestnut Street, Philadelphia. On this occasion the demonstration of the invention made at the meeting referred to was practically repeated. Besides the work actually in progress, a number of etchings were made especially for this investigation.

The invention consists in the application of an atomized spray of acid or other erodent, projected vertically upwards against the surface to be eroded by means of an air-blast, and in the combination of appliances for that purpose.

In the machine examined the blast was supplied through a receiving tank from an air pump at a pressure of from 5 to 8 pounds. The pump used was a Roots rotary air-compressor, and, in addition to this, the apparatus is composed of an etching case and a washing case. These two compartments adjoin, one in front of the other, and are fixed

over separate parts of an open shallow tank, which is divided by a partition. The compressed air passes from the air tank to the atomizers on the one hand and the washing appliance on the other, through pipes connected by two three-way cocks. These are so arranged that when one is open to let the air current pass to the aspirators, the other is open to let a supply of water pass to a water reservoir placed between them. The two cocks are joined by a connecting bar, which is actuated by a lever. A pipe connection from the first three-way cock carries the air current to a series of metal tubes placed below the bottom of that portion of the tank which contains the acid or other erodent to be used. A large number of atomizers project from these tubes, with their nozzles protruding above the surface of the liquid. The atomizers are constructed in the form of aspirators, consisting of a central tube open to the air current, which is surrounded by other tubes open to the liquid. When the air current is forced out through the central tube, it causes a vacuum in the surrounding tubes, which then become filled with the liquid to the point of the air opening, from which the passing blast carries it out in the form of a finely divided spray, in the manner and on the principle of atomizers generally. The atomized spray is driven by the blast against the surface to be etched, and then falls back into the receptacle below. The liquid is thus continuously used in the operation of the blast.

The atomizers are enclosed in a case, the sides of which are partly of glass, which makes the interior visible from the outside. On opposite sides of the interior of the case, at varying heights above the surface of the liquid, are fixed two pairs of narrow shelves, which serve to support open frames. These are movable, and are connected by a rod running through the back of the case to an arm which is actuated from the shaft of the air compressor. In each of these movable frames, and held in grooves, is another open frame, which slides out at the front of the etching box. This slide frame is rabbeted to receive a board, on the under side of which is fixed the plate to be etched. When this is slid into its place, the etching case is closed

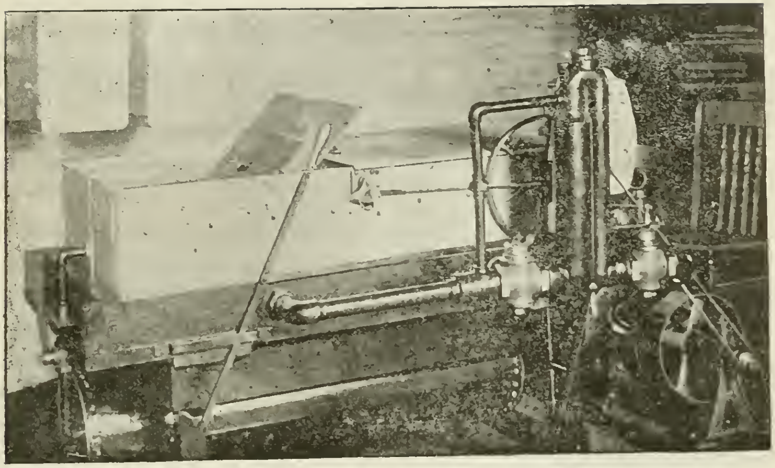
and the plate is then ready to receive the acid blast from the atomizers below it.

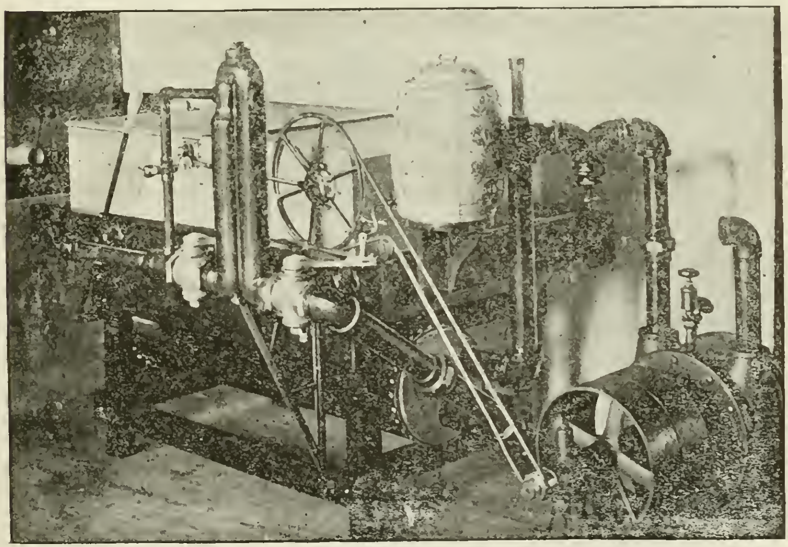
During the operation of the blast the frame with the carrier board is moved to and fro in a horizontal plane by the connecting rod and arm above referred to. The movement extends over a space equal to the distance between the aspirators, and serves to evenly distribute the action of the spray over the plate. At the same time it also gives a rocking motion to the drops of liquid which hang from the under surface of the plate, and this tends to deepen the erosion in the wider spaces of the etching and facilitates the fall of the drops.

When the etching process is to be interrupted or ended, the frame with the carrier board is slid out from the etching case to the washing compartment in front. At the bottom of this compartment are a number of perforated pipes connected by the second of the two three-way cocks to the water reservoir.

When the two cocks are turned by the lever and bar connecting them, the air current is directed to the top of the water reservoir and drives the water out through the perforated pipes at the bottom of the washing compartment, upward against the overlying plate. The water issues in a broad fountain jet and instantly washes the plate over its entire surface.

The erosion of the plate under the action of the blast of acid spray is very rapid, as was demonstrated at the Institute. In experiments made in the presence of your committee on zinc plates with nitric acid diluted to 10° Beaumé were etched in three minutes, without any undercutting, as deeply as the so-called "second etch" of the regular immersion method, which, including the four-way powdering, would take some twenty minutes at least. To erode the plate to this depth in an immersion bath with a single etch would require about ten minutes in an equally strong solution. It is, however, quite impracticable, with the bath, to carry the first etch so deep, or to force the erosion so rapidly, as the lines would be eaten away by the underetching, and the plate would become so heated by the decomposition of the





The Levy Acid Blast.

The above two plates were made on hard zinc in a single etch of one and one-half minutes.

metal that the resistant would be apt to give way. The finely atomized spray of acid, driven by the blast against the plate at a right angle to the surface, etches the metal without undercutting the protected parts. This process is the main principle of the invention, but the effective avoidance of the difficulty presented by the overheating of the plate under strong chemical action is a vital element of its successful application.

The heat developed by the compression of the air is dissipated by radiation from the air tank provided for this purpose, and from the pipes leading to the aspirators, which are submerged in the outer tank containing the wash water overflow; and, in expanding when it emerges into the etching case, it absorbs an amount of heat fully equal to that evolved in the decomposition of the metal. By this means the plate and acid are kept from becoming heated, the large evaporating surface presented by the finely-divided particles of acid especially tending to keep the liquid cool.

The theoretical basis of the application of the acid blast, as outlined by the inventor in his paper before the Institute, is regarded by your committee as substantially correct, and the considerations stated, with reference to the several advantages of the process, appear to be fully justified.

It would appear, from the records accessible to your committee, that the Levy Etching Blast is a novel and original process and appliance.

In view of the importance of this invention, and in consideration of the originality of the idea and of the ingenuity displayed in its application, the Franklin Institute awards the Elliott Cresson Medal to the inventor, Louis Edward Levy, for his "Acid-Blast Method of Etching Metal Plates."

Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, January 3, 1900.

JOHN BIRKINBINE, *President.*
WM. H. WAHL, *Secretary.*

Countersigned by
EDGAR MARBURG,
Chairman Committee on Science and the Arts.

THE FRANKLIN INSTITUTE.

Stated Meeting, held Wednesday, June 20, 1900.

PRISMATIC LIGHTING FOR THE ILLUMINATION OF DARK INTERIORS.

By Dr. Wm. H. Greene,
Member of the Institute.

The practical application of the refractive property of the lens or prism to change the direction of light rays passing through it, for the purpose of artificial illumination, originated with the French physicist, Fresnel, who first suggested its use in lighthouses, for the protection of maritime coasts, about the year 1815; and the Fresnel lens in various modifications is to-day solely used for this purpose.

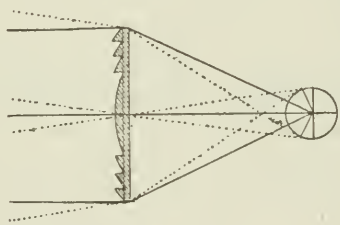


Fig. 1.

The Fresnel lens is designed for projecting a powerful beam of parallel light upon objects to be illuminated at a distance. The principle of this device is seen in *Fig. 1*, which shows a central plano-convex lens surrounded by a series of rings or segments of lenses or prisms, to which successively diminishing curvatures or angles are given in order to give them a common focus.

Within the past four or five years the application of this principle has been made, and with decided success, to the illumination of dark interior spaces, where the amount of light naturally entering therein is insufficient for satisfactory illumination, and artificial lighting must occasionally or constantly be resorted to.

The requirements of public buildings and modern office buildings, in this respect, have been most urgent, and the various devices known generally by the name of "prismatic lights" have been extensively used for the purpose and have proved so useful that in one or another form they have come to be regarded by architects and builders, not to speak of a great number of householders, as indispensable.

It is the purpose of this communication to give a brief review of the art of prismatic lighting, which, at the present time, is passing through the active stages of the course of evolution, to which all the arts are subject, in determining the survival of the fittest.

Omitting, for the present, consideration of the vault light for basements and cellars, where but one form of prism, namely, an approximately right-angled prism depending on total reflection for its utility, is admissible, there are two general methods in vogue of installing prismatic lights to meet the requirements of service.

In one of these, the sheet of prismatic glass is placed in a window-frame in the vertical position, thus taking the place of the window light. In the other, the sheet of prismatic glass is installed in a more or less inclined position, projecting outwards from the window opening. This form of construction is known in the trade as a "canopy."

The question as to which of these two forms of installation will give the best results is determined by the extent of the sky opening upon which dependence must be placed for light.

Where this is of considerable area, as for example where the windows face a wide street, the prismatic glass set into the window-frames in the vertical position will give satisfactory results.

Where the windows receive their light from a restricted area, as for example in court-yards, or the side-yards of dwelling houses, and, generally, in the many situations where high walls rising in close proximity cut off the free access of light from above, the projecting, canopy, form of prismatic glass is preferable.

Speaking in a general way, the change from the vertical

to the canopy form of installation will be indicated when the incident angle of the light falling on the window opening averages 60° from the horizontal plane.

The popularity achieved by the use of light-projecting devices of this general nature has called into existence a great number of patented inventions, some claiming special forms of prism construction (in combination, in certain cases, with a prismatic or lenticular formation on the reverse side of the glass), and of a far greater number of design patents and methods of glazing, and other matters of minor detail.

For the purpose of this communication, these minor devices may be left out of consideration, and the several generic forms of prism construction only will be given attention.

These may be divided into two general classes:

(1) Those in which the glass forming the light-projecting device consists of sheets having on one surface a series of prisms or segments of lenses of any desired angle, the back of the sheet being a plane surface, and

(2) Those in which the glass forming the light-projecting device consists of sheets having on both surfaces a series of prisms or lenses.

The prism glass most generally known and used is that of the first-named class.

The action of a section of prism glass of this construction is shown in *Fig. 2*, in elevation and plan. It is obvious that the general refracting effect of the prismatic surface in this and in the other forms of prism glass will be substantially the same, whether the refractive surfaces of the structure be straight (*i. e.*, prismatic), or more or less curved (*i. e.*, lenticular), irrespective of the angles of the prism sections or of the curvature of the lens segments. It is important, however, that these angles (or curves) be carefully considered, since upon the correct appreciation of this element the light-projecting efficiency of the structure largely depends. Improper angles (or curvatures) may greatly diminish the efficiency of the device, by the dispersion and loss of light, caused by total reflections in the interior of the glass.

There is general misapprehension regarding the proper action of light-projecting glass, which needs a word of reference. It is assumed by many that the prismatic glass should be so constructed that all the exterior light transmitted from the interior boundary of the prismatic window, or canopy, should be directed in lines substantially parallel to the boundary walls, floor and ceiling of the apartment, and that the more nearly this condition is realized, the closer will be the approach to the theoretically-perfect mode of operation. Some of the manufacturers of prismatic glass endeavor to realize this condition by varying the angles of the prisms uniformly from the center to the edges of the sheets, on the principle of the Fresnel lens.

A little consideration of what is intended to be realized by prism lighting of interiors will suffice to show that this view is an erroneous one and liable to result, in practice, in a much inferior interior illumination than can be otherwise obtained.

This criticism will be understood by stating the general proposition, that the objects of prismatic lighting are, first, to direct as much extraneous light into the interior as possible; and, second, to direct it in such manner as to derive the largest possible benefit therefrom.

In considering the relative merits of parallel and divergent light transmission by prismatic glass, it should be said that practically as much extraneous light can be directed into the interior space to be illuminated by the one as by the other arrangement of prisms or lenses. But, when we come to consider the second portion of the proposition, it can easily be shown that the system of transmitting the light in parallel lines cannot possibly be as effective as the method of divergent transmission, and more especially, divergent transmission in both vertical and horizontal planes, and for the following reason.

It is well known that the best effects in interior illumination are realized when uniform diffusion throughout the apartment is obtained. This effect can be secured most effectively only when all shadows are obliterated by calling into requisition the action of the entering light reflected

from all parts of the side walls, floor and ceiling of the apartment.

By the method of directing the transmitted light in parallel lines, the ill-effects of shadows cast by opaque objects in the path of the entering light will be realized in an extreme degree, as there will be no ameliorating influence to counteract and neutralize the shadows by reflection from the bounding walls and floor of the apartment; and an inspection of the condition of an apartment thus treated will disclose this objection at once.

By the method of divergent transmission, while quite as

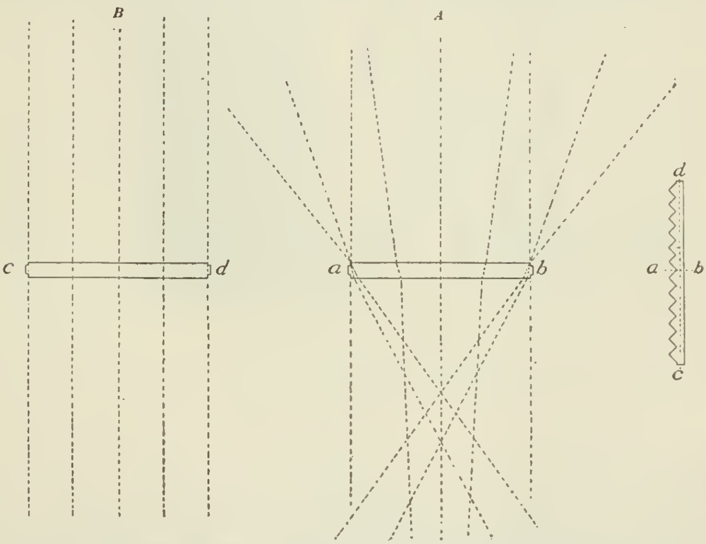


FIG. 2.

much or more extraneous light is thrown into the apartment, as by the other method, its distribution is decidedly more advantageous, from the fact that the repeated reflections from the bounding surfaces of the apartment cause the practical obliteration of all shadows and a practically uniform diffusion of the light to all parts of the interior.

Returning now to the descriptive portion of the subject, the *modus operandi* of the simplest form of a light-projecting prismatic window is shown in the plan views in *Fig. 2*, *A* and *B*, in which the light from an exterior source falling

upon the plane, outward surface of the glass is refracted at the boundary of the interior prismatic surfaces and projected into the room to be illuminated.

Fig. 2 A, which is a plan view of this construction taken on the line *a b*, exhibits the effect of the light distribution in the vertical plane from the effect of refraction from the terminal portions of the prism, where the influence of the more oblique rays is not counteracted by a modification of the angles of the prism from the center line to the upper and lower edges of the glass. *Fig. 2 B* is a plan on line *c d*, showing that the light rays are not distributed divergently in the horizontal plane, but are all directed in parallel planes.

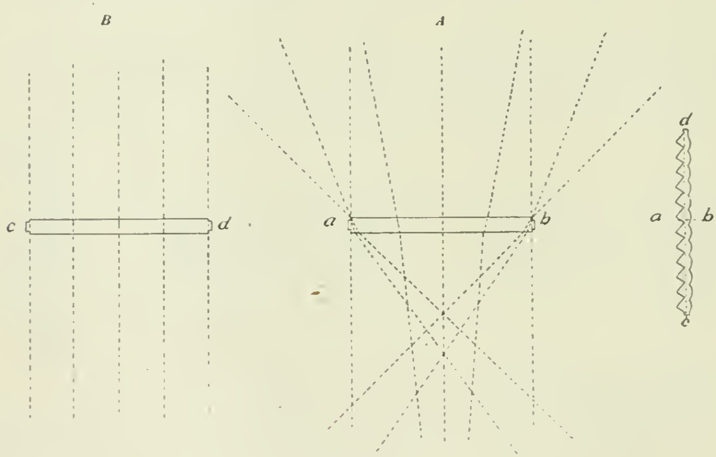


FIG. 3.

Figs. 3 and *4* represent the action of prismatic glass of the second class, *i. e.*, in which both surfaces are prismatic or lenticular.

Fig. 3 shows a form of light-projecting glass that has lately come into use, and for which certain advantages are claimed over the construction previously described. The sheets in this form of prism glass have one surface furnished with prisms—commonly placed towards the room to be lighted—and the other surface formed of a series of lenses of small curvature, distributed in panel form, *parallel* to the direction of the prisms. This construction, as well

as that shown in *Fig. 2*, manifestly exaggerates in the vertical plane the divergent distribution of the transmitted light, and consequently operates, so far as it goes, in the correct manner, utilizing the reflecting action of ceiling and floor in diffusing the light.

The construction shown in *Fig. 3* possesses one obvious advantage over the several modifications of class 1, namely, that the lenticular form of exterior surface arrests and directs into the dark interior to be lighted a certain amount of the exterior light, which, with the plane exterior surface of class 1, would be lost by total reflection from the ex-

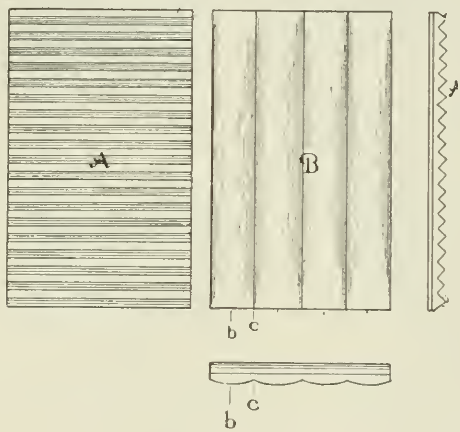


FIG. 4.

terior plane surface. Practically all of this additional light thus projected into the dark interior would be gained if the angle of the prism and the curvature of the lens panels were correctly adapted to the length of the apartment to be lighted.

The latest modification of class 2 remains yet to be considered.

In this, the interior prismatic surface of the glass is the same as that just described, but the exterior lenticular panels are arranged not parallel, but *transversely*, to the direction of the prisms. The details of this form of construction are shown in *Fig. 4*, *A* and *B*, while the *modus operandi* is best observed in *Fig. 5*, *A* and *B*.

The radical difference in the operation of this form of light-projecting glass and that of both forms previously described resides in the fact that the light distribution in this form is exaggerated in the lateral as well as in the vertical plane. This feature is illustrated in *Fig. 5 B*, in which *B* is supposed to be a section of the prismatic glass taken on the line *c d*, from an inspection of which it will be manifest that the vertical arrangement of the exterior lenticular panels will serve a similar purpose in this construction in relation to the light falling sidewise on the exterior surface of the glass as the lenticular panels in the previous case serve in relation to vertical rays; namely, to arrest and refract into the dark interior a considerable amount of light

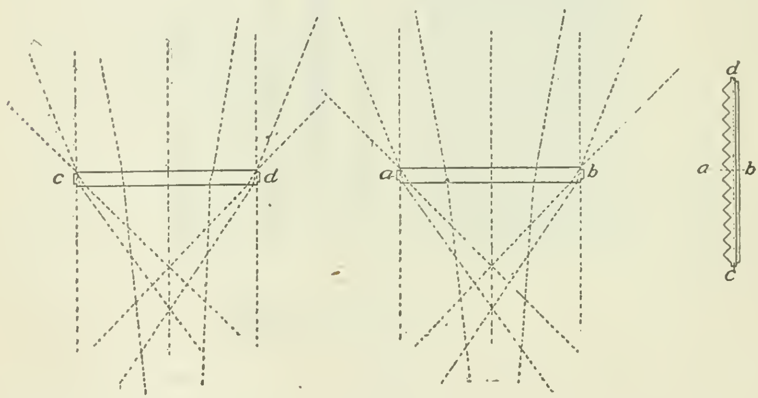


FIG. 5.

in the horizontal plane which would otherwise be lost for useful purposes. All of the light thus collected and introduced into the dark interior by the lateral collecting action of this device is so much clear gain over the devices previously described.

Further consideration will show, also, that if the interior surface of the glass be provided with prisms of uniform angle, determined in each case by the length of the apartment to be illuminated, this form of construction will secure the same advantage in respect of the vertical diffusion of the entering light as will be obtained from the lenticular prismatic construction previously described.

On theoretical grounds, therefore, the last-described

modification of light-projecting glass, belonging to class 2, should give the best results if intelligently installed. Comparative practical tests also bear out this conclusion.

An additional and important advantage possessed by prism glass of the last-named construction (namely, a prism plate constructed with prisms on one side and prisms or lens panels arranged transversely on the reverse side) remains to be noticed.

Since all illumination by means of prism glass is thrown from a comparatively low point, namely, through windows, while all other artificial illumination is directed from a point above, the shadows produced by the prisms on objects in a room constitute a disadvantage common to most systems of lighting by means of prisms, as has been noticed in what has preceded. The light-projecting glass last described, however, by reason of its diffusing quality, both in the horizontal and vertical planes, largely overcomes this objection. Where two such prism windows are used for the same apartment, the light thrown from one window completely overlaps that thrown from the other, thereby practically obliterating the shadows produced by prism lights of other constructions.

This construction also has the advantage of enabling manufacturers to produce more readily the larger sizes of prisms, from the fact that one surface has projections at right angles to projections on the reverse side, giving a bridge effect, thus adding to the strength of the plate. For this reason, likewise, it is not essential to have the thickness of the body of the glass as great as with other forms; and, inasmuch as there is a larger loss of light through absorption in passing through a thick than a thin medium, the loss of light from this cause may be much reduced.

Finally, it may be said that all the various forms of light-projecting prismatic glass accomplish, measurably, their intended purpose of considerably increasing the illumination of dark interiors over what would occur without artificial aid. In the selection of the kind of light-projecting glass and the manner of its installation, the user should be guided by the personal observation of the effects produced, rather than by the claims of rival manufacturers.

Stated Meeting, April 25, 1899.

ELECTROMAGNETIC MECHANISM, WITH SPECIAL REFERENCE TO TELEGRAPHIC WORK.

BY R. A. FESSENDEN.

(*Concluded from p. 80.*)

This means that all such devices as tapering cores, or plungers in unarmored solenoids, should not be used, and must be supplanted by types like the following, *Fig. 6, a, b*

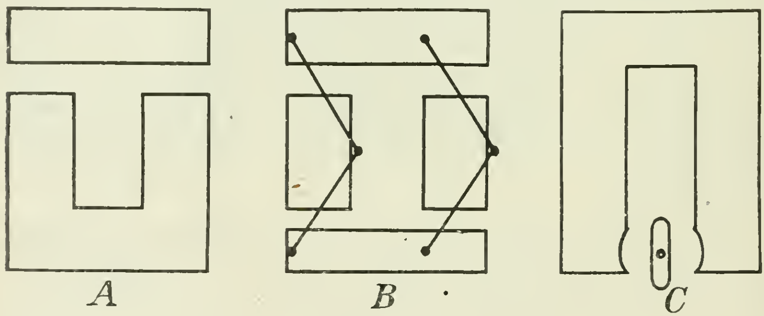


FIG. 6.

and *c*. Of these, however, there is only one which is worth considering, *i. e.*, *c*, the others all being markedly inferior to it in all respects.

In designing this, we may be guided by either one of two considerations :

(1) Efficiency.

(2) Energy for given weight of moving part for given angular motion, *i. e.*, torque per gram.

Taking, first, efficiency, we see at once that by Rule I, the flux through the armature before it begins to move should be small compared with that when the armature has ended its motion. Suppose we wish to get 80 per cent. of the

theoretical efficiency, *i. e.*, 40 per cent. of the total energy spent, then since the energy available is

$$\frac{1}{2} L I^2$$

and L I equals the linkages $P n$ and n is constant, then, P should be only 20 per cent. in the first position of the armature of what it is in the last position.

But when we are working the iron economically, practi-

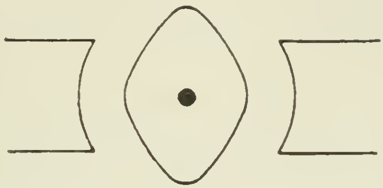


Fig. 7*a*.

cally all the reluctance is in the air gap. How to calculate this most efficient point will be given later; at present suppose it to be where $\mu = 2{,}000$ and that the air gap is but 1 millimeter in length, the length of the magnetic circuit being 10 centimeters. Then we see that the reluctance in the iron is only one-thirtieth of that in the air, so that practically we can neglect the iron, and the flux will

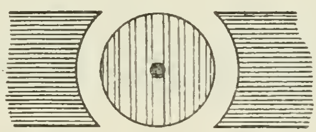


Fig. 7*b*.

be inversely proportional to the length of the air gap.

This being the case, we see that the air gap must be five times as long before the armature has started as when it has come to rest. We can arrange this in several ways, for instance, as shown in *Fig. 7a*.

But there is one objection to this form, and that is that the flux is apt to have a higher density just as the armature reaches the pole tips, and this means hysteresis and uneven

pull. Moreover, we should have as little inertia in the moving part as possible, for that means, as pointed out previously, more loss. Now, of all forms the cylinder is that which has least moment of inertia, and fortunately it is that which can be made to give the best distribution of lines. Construct a cylinder, as shown in *Fig. 7b*, of laminated sheet iron, the laminations being horizontal and separated by sheets of non-magnetic material equal in thickness to the sheets of iron. Still better would be the use of layers of wire, japanned and embedded in vulcanized rubber or similar material, but in most cases this would be too expensive.

It is evident that we must have the air gap between each pole piece and the armature equal in length to one-eighth of the diameter of the armature, for in this case the reluctance will be five times as much when the laminæ are perpendicular to the lines of magnetic flux as when they are parallel.

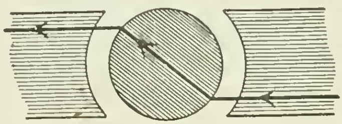


FIG. 8.

This is only approximate, as when the laminæ are parallel the effective area of the air gap is only approximately double the cross-section of the laminæ. If, of course, there were no spreading of lines from the edges of the laminæ, the area would be smaller, but the spreading gives practically the full area.*

It is evident that the change of flux will be gradual, as when the armature has turned through 45° the lines have to pass diagonally across the laminæ and not as shown in *Fig. 8*.

Supposing, then, that we wish to design a mechanism to do a given amount of work, say 1 joule, and we have the voltage given as 10 volts. The efficiency being 40 per cent., then we need $\frac{100}{40} = 2{\cdot}5$ joules.

* I have since found that the approximation is very close indeed.

If the resistance of the circuit be taken at 1 ohm, and I as 10, we get

$$\frac{1}{2} \text{L} I^2 = \text{L} \times 50 = 2{\cdot}5 \text{ or L} = {\cdot}05$$

which, since we have taken I in ampères, and work in joules, will be in henrys, and equals

$\cdot 05 \times 10^9 = 5 \times 10^7$ linkages per unit current, or total linkages L I, equal

$$5 \times 10^8 = \text{lines} \times \text{turns}.$$

If we take the armature as of square cross-section, perpendicular to the flux, and (the length of side being x) wish to work the iron at 10,000 lines (which, since only one-half of the cross-section is iron, is a flux density of 5,000), we get, since the length of the air gaps is one-quarter the diameter of the armature,

$$5{,}000 \times \text{x}^2 = P$$

$$\frac{\cdot 4 \pi n I}{\frac{1}{4} \text{x} \div \text{x}^2} = \text{flux} = 5{,}000 \text{ x}^2 = \frac{5 \times 10^8}{n}$$

whence since $I = 10$

$n = 450$

$\text{x} = 4{\cdot}5$ approximately.

This is the best mechanism of this class which it is possible to make to do this work, for the following reasons:

(1) The moving part has the least amount of inertia possible.

(2) There is the greatest return, for energy expended, possible for mechanism of this class.

(3) It is the lightest for equal efficiency, and if this be lowered, can be altered so as to be lighter than any other mechanism of the same class to do the same work.

(4) It gives the least amount of material possible, if the flux is properly determined as by the methods given below. It has also other important advantages, the chief of which is this. In most mechanisms what is needed is a large force at first and practically none at the end. In the usual

methods, if the force be strong at first, it necessitates much waste of energy, as shown above (Rule I), and the pull is strongest at the end where it should be weakest (otherwise the armature goes on gathering up momentum, which is lost, unless it is desired to obtain a hammer blow, as in striking bells). But in the above type, by attaching a crank or cam to the axle so that the crank is in line with the arm to be moved, the slight force at first exerts the greatest leverage just when it is needed. Moreover, by suitably spacing the layers of iron and non-magnetic material in the armature and field, the pull may be made to follow any law desired. A convenient form is shown in *Fig. 9*, where *W* is

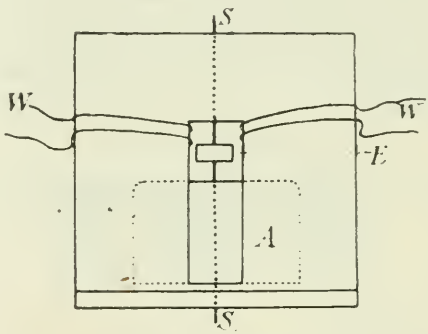


FIG. 9.

the wire, *A* the armature, *S* the shaft, and *E* an eccentric, which gives the pull.

Again, it is possible to obtain more energy out of it than

$$\frac{1}{2} L I^2$$

in the following way. Wrap around the field a short-circuited coil of very low resistance. On putting the current on, it will exert some detrimental effect, *i. e.*, waste some energy.* Before the armature has come to its final position, break the circuit. An induced current will

* As much energy must be wasted in $I^2 R$ losses in the short-circuited coil as is equal to the energy gained by the use of the short-circuited coil. Hence, this gain is in weight, not in efficiency.

be set up in the coil *D*, and this will tend to keep the flux constant. But the energy of the flux, which is practically all in the air gap, equals

$$\frac{\text{flux} \times \text{gilbertance}}{2}$$

The flux remains the same, but if the armature moves on the gilbertance will be less. Consequently the armature is forced on, and this energy [one-half flux $\times$ (original gilbertance — final gilbertance)] is gained as mechanical energy, and at the same time the sparking is very greatly reduced.

The field should be of laminated iron, and in the same plane as the shaft of the armature.

Suppose it be desired to increase the force with the same armature, at the expense of a slight loss in efficiency. We can do it very simply. Remembering that practically all the stored energy is in the air gap and that the energy we can utilize is numerically equal to this, suppose we wish to get double the energy, all we have to do is to double the length of the air gap. A little of this will be lost, as now the flux in the first position of the armature will be a larger fraction of that at the end than before, and this is where an additional loss of efficiency comes in, the initial L being say one-third of the final L.

But we need no greater voltage or current than before and no greater $I^2 R$ loss, as all we need to do is to use double the turns and wire of twice the diameter. This will necessitate lengthening the magnetic circuit, but that is no matter, as the reluctance there will still be negligible compared with that of the air gap.

We will now have double the work for the same motion, and in many cases this is appreciated more than a small gain in efficiency. It is sometimes thought that force is gained in such cases by increasing the induction, the increment varying as the square of *B*. This, as will be seen from what I have shown, is a mistake, the work done for given motion, and therefore the average force, varying directly as *B*, *i. e.*, in the case where the gilbertance is fixed in amount. For, if we halve the air gap,

and so double the flux, the energy per cubic centimeter in the air gap $B^2/8\pi\mu$, is quadrupled. But there is now only half the volume in the air gap, hence the total energy in the air gap is only doubled, and since, as we have seen, the available mechanical energy is equal in amount to that stored up in the air gap, by doubling our induction we have only doubled the mechanical energy. Of course, as we increase the flux, keeping the air gap constant in length and area, the average force does increase as B^2, but this is due to the fact that the gilbertance is being increased too, and it is much better to increase our force by simply lengthening the air gap, keeping the current and $I^2 R$ loss the same, than to do so by crowding the iron, which cannot be

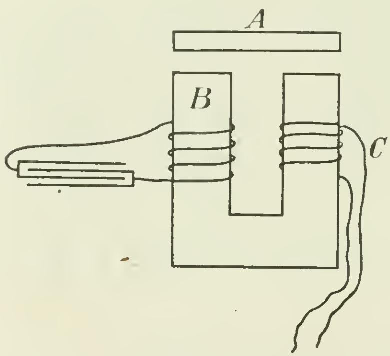


FIG. 10.

done in any case, *i. e.*, if working at 10,000, it cannot easily be pushed above 15,000, while it is a simple matter to increase an air gap from $\frac{1}{8}$ to $\frac{1}{4}$ inch, thus getting the effect of 20,000 weberivity.

The following devices may be of interest. In certain instruments the armature approaches closely to the fields, and is apt to remain there unless pulled back by a powerful spring, and energy is of course lost. A much weaker spring can be used with either of the following devices:

I. In *Fig. 10*, *A* is the armature, *C* the operating coil and *B* a coil of many turns, connected to a condenser. In breaking the circuit *C*, a voltage is set up in *B*, and the condenser is charged. If the circuit is properly tuned, the discharge

from the condenser will tend to demagnetize the circuit and make A let go. Useful for telegraphic instruments.

II. Use a part of the kinetic energy stored up in the armature to free the armature itself. Thus, attach a light arm, with a small weight on it and hinged to A, so that A stops before it does, whilst it goes on and, by its reaction on finally striking its stop, throws A back. This is not so good, however, and if a spring be properly adjusted, it is almost as efficient.

In the first-mentioned device, if a band of copper be placed about the armature it will help the throw-off, but is bad during the approach.

In all that has been written above, the time constant of the circuit has been neglected. The time constant, or the time taken by the current to rise to all but the $1/\varepsilon$ th of its full value (ε, being the base of the natural logarithms) is, as is well known, for constant effective voltage applied, equal to L/R. If, therefore, we have, with a current of 3 ampères, 9 henrys linkage, the resistance of the circuit being 5 ohms, this time is

$$\frac{9}{3} \times \frac{1}{5} = \frac{3}{5} \text{ seconds}$$

and the apparatus cannot, of course, under these conditions make two movements per second, as at the end of three-fifths seconds the current has only reached 1/2·7 of its full value (in fact less, as this is the amount it would have reached if there had been no back voltage in the coil due to the movement of the armature). Just how much less can be found by taking the mechanical work done, velocity, etc., at every point in its path, which is quite a complicated thing. In most cases, however, the time constant need not be more than doubled to allow for this. In the next three-fifths seconds, or after six-fifths seconds from the start, there will be but

$$\frac{1}{\varepsilon} \times \frac{1}{\varepsilon} = \text{about } \frac{1}{7}$$

of the full value of the current lacking, which is close enough for such work. So that, with the above values for

L and R, the current would not reach its full value in less than $12/5 = 2{\cdot}4$ seconds, and consequently could not make more than about one stroke in three seconds.

To have a low time constant means that you must have a high resistance or low self-induction. But since the work we get is

$$\frac{1}{2} \mathrm{L}\, I^2,$$

if we take L as one-quarter of what it was at first, we must have twice the current. But $\mathrm{L}\, I^2$ is the power put into the coil, half of which,

$$\frac{1}{2} \mathrm{L}\, I^2,$$

we get as mechanical work and half of which is lost at the instant of sparking. Also $R\, I^2$ is proportional to the power wasted in heating the coil (proportional, because the current is not steady, but if we double I, and it varies in the same way, we get I^2 times the heating), so that our efficiency is

$$\frac{\frac{1}{2} \mathrm{L}\, I^2}{\mathrm{L}\, I^2 + c\, R\, I^2\, t}$$

where t is the time the current is on, *i. e.*, the time of the movement of the armature. It is, therefore, apparent that all we have to do to keep the efficiency constant is to keep $R\, t$ a constant. If, therefore, we wish to make the mechanism work in one-quarter the time, add three times as much resistance to the circuit, and it will be just as efficient as before.

This seems at first glance foolish, for we must then have four times as much voltage as before, and the $I^2 R$ loss is four times as great as before, so one might think the efficiency must be lower. But the reason is that the given amount of mechanical work is done in one-quarter the time it previously was, so that though the $E\, I$ and $I^2\, R$ power are four times as great as before, yet t is only one-quarter, so that $E\, I\, t$ and $I^2\, R\, t$ are the same, and so the ratio work got out ÷ work put in is not altered.

Since I^2 enters into both numerator and denominator, it is evident that the efficiency is independent of the current. But if we double I, we can reduce L to one-quarter of what it was before and still get out the same work, and in this case, to keep the efficiency the same we must have $R I^2 t$ the same. But if I is doubled, then, since L / R is proportional to t, if we wish to have $\frac{1}{4}$ its original value, R must remain the same. Here, then, as before, we must increase the voltage, in this case, however, only to double of what it was before, the power $E I$ and the heating $I^2 R$ being quadrupled as before, but the efficiency being the same.

To get $L I^2$ the same, with $L\ 1/4$ and I twice their previous values, means that $L I$ is halved. This means that if we keep the turns the same we must quadruple the length of the air gap, or take a quarter of the cross-section of the iron, the latter, of course, being preferable, as it makes the armature only weigh $\frac{1}{8}$ as much as before, and its moment of inertia, if of the circular type, is but $\frac{1}{32}$ of the original figure.*

Thus it happens, fortunately for telegraphic work, that at the same time that we reduce the time of movement we reduce the moment of inertia, thereby giving a greater yield of mechanical work in the way needed. This also gives the least amount of hysteresis loss.

It is to be noted that this additional voltage can be got in some cases by means of a condenser, for instance, if an alternating current be used. Another advantage in working with somewhat large air gaps is this: Suppose the original air gap to be 1/25 inch. Owing to necessary mechanical imperfections, there will be a certain amount of

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* We could, of course, instead of keeping the turns the same, take half the number of turns and keep the air gap the same. If we choose to follow the rule that the impedance of the receiving instrument should equal the impedance of the line, then the problem becomes perfectly determinate. But this rule is not to be followed in most cases. For instance, in long-distance trunk lines it is best to use a high voltage, say 200 to 1,000 volts; in fact, to treat such lines, as I have put it elsewhere, as long distance transmission lines, and use most of the voltage up in the instrument and very little in the line. For cables the case is different in some ways. The whole question is somewhat complicated, and will be dealt with in another paper.

backlash. If this be 1 / 50 inch, we are only getting the benefit of a 1 / 50 inch air gap, while expending the energy of a 1 / 25 inch; *i. e.*, throwing away half of the energy, our total efficiency therefore being less than 25 per cent. With longer air gap, this loss is not so great; *i. e.*, with 1 / 10 inch, a backlash of 1 / 50 inch would only increase $L I^2$ 20 per cent., and our total efficiency would be 40 per cent.

Class III. In this class the magnetic field is constant, whether permanent or electro-magnet be used, and its efficiency may reach nearly to 100 per cent., and so is more than twice as efficient as mechanisms of Class II. Moreover, the total weight is sometimes lighter, as, with a given magnetic circuit, exciting winding, and armature, we see that, if the mechanical energy obtained by letting the armature move, in a mechanism of Class II, is

$$\frac{1}{2} P n I$$

then by narrowing the air gap 10 per cent. and putting the wire now no longer needed on the fields into the shape of an armature coil, it will be capable of doing mechanical work numerically equal to

$$2 P \times \frac{1}{10} n \times 10 I = 2 P n I,$$

or four times as much as before, with the same voltage, or, if we keep both current and voltage the same, and put half the turns on the armature and decrease the air gap to 1 / 2, then

$$2 \times P \times \frac{1}{2} n \times I,$$

or twice as much as before. The time constant may be made practically zero, for, if we saturate the magnetic circuit, the permeability will be extremely small.

Considering, however, the weights of the moving parts, in Class II the energy is practically all in the air gap and equal in amount to

$$\frac{B^2}{8 \pi} \times \text{length of air gap} \times \text{cross-section of air gap.}$$

Taking the length of the air gaps as together equal to one-quarter the armature diameter, we have, x being diameter of armature,

$$\text{energy} = \frac{B^2}{8\,\pi} \times \frac{x^3}{4}$$

Total volume of armature is

$$\frac{\pi}{4}\,x^3$$

∴ energy per cubic centimeter of armature equals

$$\frac{B^2}{8\,\pi^2}$$

and the energy per gram weight of armature is independent of its size. Since only half the volume of the armature is iron, the energy per cubic centimeter of iron is

$$\frac{B^2}{4\,\pi^2}.$$

In Class III, however, the force on the wire is

$$B_1 \times \text{length} \times \text{current}.$$

Taking the current density as 500 units (5,000 ampères) per square centimeter, and the coil as square in shape, then if the wire moves in an air gap of length x and width $\frac{1}{8}\,x$ (the maximum volume efficiency being evidently got when the wire is all outside the gap when it starts, and all outside when it ends its motion), we have,

$$\text{work} = B_1 \times 2\,x^2 \times \text{current}.$$

The volume of copper is

$$4\,x \times \frac{\text{current}}{500}$$

The work per cubic centimeter of copper is therefore

$$\frac{B_1\,.\,x^2\,.\,\text{current}\,.\,500}{2\,H\,.\,\text{current}} = 250\,B_1\,x.$$

But B_1 is here twice B for Class II, and we get

$$500\,B\,x.$$

If B is 10,000, we find (if we take the mean density of the iron sheets, plus the oxide and air spaces as one-half that of the copper), that the amount of mechanical energy given out by equal weights of moving parts are equal when

$$500 \, B \, x = \frac{B^2}{4 \, \pi^2}$$

or,

$$x = \frac{1}{20} \text{ centimeter.}$$

Thus, when the diameter of the armature in Class II and the diameter of the coil in Class III are each $\frac{1}{20}$ centimeter in diameter, they will give equal amounts of energy per gram of moving parts. The iron will have less moment of inertia, however, so that roughly we may say that, for a given output,

Above $\frac{1}{10}$ centimeter Class III is best.

Below $\frac{1}{10}$ centimeter Class II is best.*

This shows us why, with a given length of period, we can never obtain the same sensitiveness in a copper coil galvanometer as in an iron armature one.

I might mention the following device for preventing sparking in oscillatory magnetic mechanisms used with direct currents. I was called in to advise some men who had an electric reciprocating pump and who were having trouble with sparking. They were trying to get over it by shunting it round resistances, so as to make the current a sine curve. This, of course, was a very inefficient way. I suggested the device shown in *Fig. 11.*

N S is a permanent of electro-magnetic circuit, and A and B coils mounted on a tube which can move horizontally, and surrounds an iron core. Make the current in A and

* It is, however, assumed here that the flux density in Class II is half that of Class III. For different ratios of B these diameters would be slightly different.

it will drive the tube to the right. Just before breaking *A*, short-circuit *B*. Then break *A*, A current will be set up in *B* and there will be practically no spark at *A*. This current in *B* will tend to drive the tube to the left, and will thus act as a sort of electric buffer, or as the equivalent to an air cushion or spring.

S. P. Thompson's method, "Electromagnet," p. 278, can also be used for this purpose, and is a very good one. It consists in using two windings which oppose each other, and producing a magnetic flux by opening one circuit, when there is, of course, no spark.

DESIGN FOR LEAST COST OF WIRE IRON AND LABOR.

The chief item is of course the last, unless American methods of manufacture be used, and this depends upon

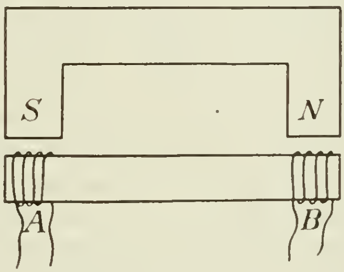

FIG. 11.

how many have to be made. It is a curious and instructive thing to notice how the methods which were put in use for the cheap manufacture of common things were finally extended under pressure of competition, necessitating more and more accurate work, till finally, greater accuracy is now reached in the manufacture of large parts of machinery than used to be reached by the old watchmakers. I remember visiting Maxim seven or eight years ago, when he was in the midst of his work on the flying machine, and on asking him how he liked England after the old place at Newark, I learned that England was a land "where every prospect pleases and only the machinist is vile." He could not get them to understand the meaning of the $\frac{1}{1000}$ of an inch,

and consequently when he would order material 2 inches in diameter it might be 2·01 or 1·99, a thing he did not appreciate after having had men who worked regularly to 0·0002 inch, and the fit of whose work would be altered by laying the warm hand on it.

Thanks to the Universal Grinder, and other machines never seen outside of America,* the production of accurate dies is a very easy matter, and this reduces the cost of manufacture to very little for most of the parts, including all the iron parts, as these must be in sheet form. For the other parts, turret lathes, jigs and form millers will do much work at low cost, but as a rule it may be said that for most work the method now coming into use, which depends upon the discovery of a process for casting hard and cheap alloys of the most complicated forms to size within $\frac{1}{1000}$ of an inch, is bound to extend itself. I have seen work, with surfaces lying in ten or eleven planes at different angles, with more than a dozen threaded screw holes, and all kinds of slots and openings at all sorts of angles, so that it would have taken a skilled American workman nearly a day to finish it (with jigs for clamping it on the machines in proper position all made beforehand and in place on the machines; or a full week without jigs, adjusting the piece to each machine by hand, to the degree of accuracy required), made all complete, correct to $\frac{1}{1000}$ of an inch, with not even a burr on a screw thread, so that any one of a thousand would fit into place with only a touch of a file to remove a parting mark, and costing for manufacture but *two* cents.

Of course, the dies are expensive, as they must be finished very carefully, and the casting is done under pressure and with non-expansible alloys of very hard and tough texture. But the cost of the dies will, in all but the very simplest cases, be rather less than that of the machine jigs, and, of course, the interest on machines, floor space and time of workmen are saved. I look for this to be the next great labor-saving advance.

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* This was written in 1898.

I cannot, however, go into the question of the methods of cheapening cost of manufacture, as that is an art by itself and one which takes considerable experience to learn. Of two men equally skilled in the knowledge of handling machinery, one will build a thing for $10, the other for a fraction of $1, the difference being due simply to differences in design, in making one part accomplish several functions and in making it direct and simple, though each apparatus may do exactly the same thing and in the same way. To designers I would say, work hard and all the time. Never let a piece of apparatus pass without seeing exactly how it functions, what the central idea was, how it was carried out, how you would have carried it out, how many operations and settings there were on it, what it must have cost, and, finally, whether you would have chosen that method at all. Moreover, read widely, and never lose a change in going over small shops, as some of the most ingenious devices in the world are in such places. I do not mean to say steal other men's ideas, because the fount of honor is in the commercial element of a nation, and spreads from thence, so that ideas of morality alter with conditions of trading, therefore we should be careful not to do anything which, if widely followed, would be injurious to the conduct of business. But form your mind by these good conceptions, just as the artist forms his by the inspection of masterpieces. And in doing so you will notice finally, after years of work, that your designs build themselves up like a piece of sculpture. Just as each individual part of a statue may be well done, and it yet does not hang together from different points, so that the impression of the whole is incoherent and repels; so a design is not good, however excellent the details, unless it gives that sense of complete adaptation of means to end which stamps the perfect conception. The designer is really an artist, in the higher sense of the word, in that his creations strike one with a keen thrill of intellectual joy, instead of appealing to the lower and more material senses and emotions. This artistic nature of the work is shown most markedly by the opportunity which is given the individu-

ality of the designer to assert itself, so that an experienced designer will say at once, on seeing a machine, "That was designed by so and so," or, "was modelled after his style by a man who had worked in such a place."

As regards economy of cost of copper and iron, that is, as a rule, easily solved. The method followed of late years in most American shops, where the designers are almost all university men, is that of designing the apparatus with a given set of dimensions and estimating the cost, then designing another and making another estimate, and so obtaining a rough curve from which the best size is chosen by the designer. Of course complete designs are not made, but only enough to get an idea of the cost. There are, however, always a great many variables, and sometimes a mathematical formula shows which are the proper things to take as variables, as for instance in the above discussion on the method of building apparatus of Class II for quick action.

To do this we need to know the relation between magnetic flux and magnetic force. This is given by Kennelly's law

$$\nu_i = \alpha + \beta H,$$

that the intrinsic reluctivity ν_i is equal to a constant plus another constant times the gilbertivity H.

The intrinsic reluctivity is defined as the gilbertivity divided by that part of the weberivity due to the iron; *i. e.*, $B - H$, therefore,

$$\sigma = \frac{H}{B - H}$$

For practical weberivities H is small compared with B, and hence σ is practically equal to the reluctivity

$$\frac{H}{B}$$

This law occupies the same place in the magnetic circuit as Ohm's law does in the electric circuit; and is incidentally of great importance in that, as I shall show elsewhere, it enables us to decide between the different theories of

electricity. From the original law we may derive the following formulæ, which I have given elsewhere:

Since

$$\sigma = \alpha + \beta H \tag{1}$$

$$\sigma = \alpha \, \Sigma_0^\infty \, \beta B \tag{2}$$

$$\sigma = \alpha / (1 - \beta B) \tag{3}$$

$$B = H / (\alpha - \beta H) \tag{4}$$

$$H = \alpha B / (1 - \beta B) \tag{5}$$

$$\cdot 4 \pi n I = P \left[\frac{\alpha l p}{s - \beta P p} + \frac{\alpha' l' p'}{s - \beta P p'} + \right] \tag{6}$$

$$\frac{dB}{dH} = \frac{\alpha}{\sigma^2} = \alpha / (\alpha + \beta H)^2 = \frac{\alpha B^2}{H^2} \tag{7}$$

In Formula 6, which is for a compound circuit, such, for instance, as that of a dynamo, P represents the flux through the armature, l, s, α, β and p, the length, cross-section, coëfficients of the iron and leakage coëfficients of the different parts of the circuit.

The following are a few values of the coëfficients for different brands of iron:

Material.	α.	β.	Observer.
Sheet iron, A.	·0002375	·0000595	Author.
" " B.	·0002275	·0000654	"
" " C.	·00033	·000064	"
" " D.	·000213	·000056	"
Cast steel, A.	·00045	·000051	"
" " B.	·000315	·0000563	"
Wrought iron.	·00022	·000058	Hopkinson.
Mitis iron.	·00025	·0000575	Author.
Cast iron.	·00103	·000129	Hopkinson.
Improved cast iron.	·00090	·000106	Author.

It will be observed how much magnetic calculations are simplified by this law of Kennelly. We have also Steinmetz's formula for hysteresis, *i. e.*,

Loss per cubic centimeter per cycle $= \eta B^{1 \cdot 6}$.

It will be of interest to note that I have found that α, β and η are connected by the simple equation

$$\frac{\eta \beta}{\alpha} = \cdot 0007$$

which holds approximately for all brands of iron, from the softest transformer to the hardest tool steel, and thus, by making but two measurements of H and B for a sample of iron, we can derive all its properties. As I have learned that Dr. Kennelly has recently discovered other relations which show us what the physical meaning of Steinmetz's law is, it will be apparent that this difficult question is now pretty well cleared up. With these two equations and a knowledge of the watts per square centimeter which can be radiated by apparatus of the type we are considering, it

FIG. 12.

is simply a question of determining minima to ascertain the most economical cross-sections, etc. As I have elsewhere* given the method of doing this, I will not take it up now.

SPECIAL TYPES OF APPARATUS.

The sensitiveness of galvanometers is an interesting question, and, consequently, from what has been said above, it will be seen that a minute flattened head of very soft iron wire, suspended by a very long quartz fiber, the magnetic field being produced by the current it is desired to measure,

**Electrical World*, August 24, 1895.

as shown in *Fig. 12*, would be much more sensitive than any other kind if it were not for hysteresis. The air gap, of course, can be long, and the ring small, which will greatly reduce hysteresis, and prevent the bead sticking to the pole pieces.

The d'Arsonval galvanometer belongs to the third class, as also does the Kelvin, in the latter case the field being movable instead of the coil.

D'Arsonval galvanometers are very often wrongly rated. This is because the true equation for the motion of the coil is not complete, as generally given. As given, the terms mean that the impressed force is used up in accelerating the motion of the coil, in overcoming the air friction and in overcoming the restoring couple of the coil. There should be another term expressing the fact that a galvanometer is really a motor, and exerts a back voltage. The full equation should be

$$a \frac{d^2\theta}{d t^2} + (b + c) \frac{d\theta}{d t} + d\,\theta = 0.$$

To show how the neglect of this term gives entirely erroneous results, take a d'Arsonval, put it in series with a very large resistance and a 1-volt battery. Increase the resistance till we get a deflection of 1 millimeter on a scale 1 meter distant. Suppose the resistance to be 10^8 ohms. Then that is given as the sensitiveness if the period be ten seconds. But this figure is entirely and absurdly incorrect. The reason is that when we throw on the battery, the coil begins to move and generates a counter voltage, with the result that the voltage piles up at that spot, as it would with a motor, and we really have, say 10^{-5} volts there, instead of 10^{-8}, until the coil has slowed down. Of course, if we had simply applied 10^{-8} volts we would not have got anything like 1 millimeter deflection in ten seconds, as it might take several minutes. Now this is what happens when we use a d'Arsonval between the arms of a Wheatstone bridge, and to show that this matter is one of considerable practical importance, I would say that I have in my laboratory a d'Arsonval which has with some bridge ratios only 3 per cent.

of the sensitiveness obtained by the first method. The best d'Arsonval, therefore, is that which has the fewest turns and the finest suspension and the strongest field. For suspensions I would recommend phosphor-bronze wires or strips, as suggested by Ayrton and Perry, drawn as fine as possible, and annealed in a high vacuum by passing a current through it, as suggested by the writer (Mal. Phys., Frank. Inst., Feb. 14, 1896).

In Kelvin galvanometers, the needle is the most important point. Tubular needles were used by Prof. Very in designing the galvanometer used by Langley and have

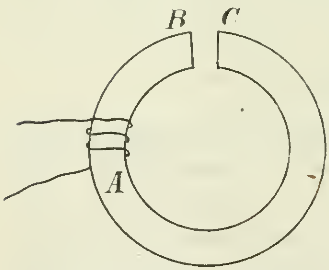


Fig. 13*a*.

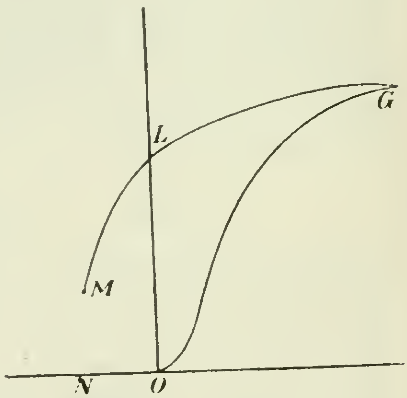


Fig. 13*b*.

since been generally adopted. The reason why tubular magnets are better than solid does not seem to be known generally, consequently it may be of interest to give it, using a method devised by Kennelly for determining the length of air gap to give the proper factor of safety for permanent magnets. This, put shortly, is as follows:

Magnetize the ring *A*, with air gap *B C*, *Fig. 13 A*. The induction will reach the point *G*, *Fig. 13 B*. Take off the current and it will fall to *L*. Now, if the air gap is 0·01 centimeter long and 50 centimeters area, its reluctance will be 1 / 5000. If the total flux at this point *L* is 15,000, this will mean that there is a gilbertance of 15,000 × 1 / 5000 = 3 between *B* and *C*, and we will take the potential at *B* as the

higher. Then there will be 3 gilberts trying to drive the flux from B to C, across the gap and also around the iron from B to A and A to C; *i. e.*, this gilbertance will exert a demagnetizing action. Therefore the flux will fall from L to some lower point M, where the demagnetizing force, *i. e.*, the gilberts necessary to force the flux OM across the air gap, will be less than 3. If now, when the flux across the air gap is NM, the gilbertance across the air gap is ON, it will

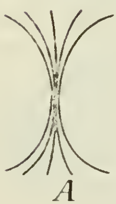


FIG. 14*a*.

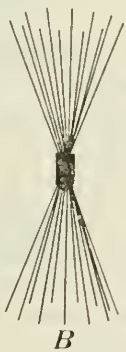


FIG. 14*b*.

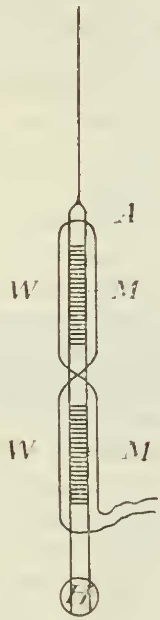


FIG. 15.

not fall any further, as, if it did, the gilbertance across the air gap would be less than ON, and the point would tend to ascend the curve.

To apply this, suppose we magnetize a little magnet and, taking it out of the field, the flux at once falls till the gilbertance required to drive it across the air gap equals the demagnetizing gilbertance required to reduce the flux in the iron to that amount. How can we increase the remanent flux? Evidently by decreasing the reluctance through the

air, which we can do by giving greater area of cross-section at the junction of the iron and air.

This is what we do when we make magnets in the form of tubes.

Here is an interesting experiment. Magnetize a piece of darning needle, say 1 inch long, and suspending it, note its time of vibration in the earth's field. Then attach two very thin discs of pure sheet iron (very light), magnetize it again and take its time again. It will be found that the permanent magnetism is now from two to three times what it was before.

Evidently, considering this point alone, the most efficient magnet system for a Kelvin galvanometer would be as shown in *Fig. 14, A*, made by winding the wire on a round bar, tempering it and then cutting it (this better, though harder to do, than cutting and then tempering), then assembling and magnetizing. Still better is what I call the wheat sheaf magnet, *Fig. 14, B*.

All this, however, is on the assumption that the magnet is so long that the magnetic reluctance between the poles is determined solely by the size of the pole ends, and not by their distance apart. If, as is generally the case, this is not true, the question of the distribution of the lines comes in. Instead of the lines radiating uniformly from the poles, with short magnets, they are forced out and must take a longer path. It is evident that this is an advantage, as lines which would otherwise return to the other pole without linking themselves with the coil will now be forced to cut the coil. Theoretically, we could accomplish this leading out of the lines by putting thin sheets of iron between the layers of the galvanometer coil, if it were not for hysteresis. The next best thing to do is to use a magnet as short as possible and with as great magnetic hysteresis as possible. As tungsten steel has very great retentiveness, we can use quite a short, thick magnet compared with what we would have to use with ordinary steel, and so, for equal moments of inertia and weights, the short magnet would be much better. It is almost impossible to arrive at definite results, but with tungsten steel as at present supplied the proper form seems to

be that of an ellipsoid, with the major axis 1·5 times the lesser axes. A particularly promising form of galvanometer is that shown in *Fig.* 15, where *A* is a thin strip of mica, about a millimeter wide, *MM* are magnets fastened to the mica with a non-buckling cement, say beeswax with a few drops of glycerine, as used by Rowland, and *W W* are the windings and *H* the mirror. The magnets should be of tungsten steel, a few thousandths of an inch in diameter, with an *L*-shaped bit at the bottom of the mirror.

Another very promising form of galvanometer, in spite of the hysteresis, is that shown in *Fig. 16*, where *W W* are

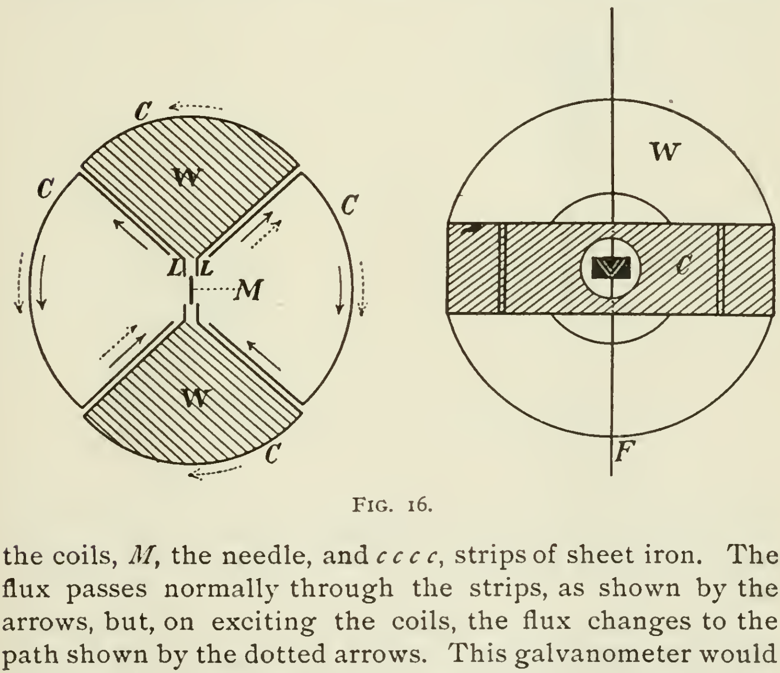


FIG. 16.

the coils, *M*, the needle, and *c c c c*, strips of sheet iron. The flux passes normally through the strips, as shown by the arrows, but, on exciting the coils, the flux changes to the path shown by the dotted arrows. This galvanometer would be of no use for quantitative measurements, but should be good for a telegraphic receiver.

The telephonic receiver belongs to Class III, but here it is a question of force rather than of work, as the telephone diaphragm does not move appreciably. Two of my students, Messrs. Bright and Davis, found some years ago that the motion of the diaphragm is certainly less than $\frac{1}{10000}$ of an

inch, and Barus later found that its motion was smaller than the wave length of sodium light. This force depends, of course, upon B^2. When the coil is not excited, the lines pass from S to S^1 (*Fig. 17*) through the air. The pole piece S being of soft iron, the drop of magnetic potential along it is small, and only a very small opposing gilbertance generated in the coil C will divert the lines, so that some of them pass from N to S at bottom of magnet without going through S at top of magnet and linking with the coil, thus reducing the value of B^2 at the air gap between S and the diaphragm.

Theoretically, still better results should be obtained by

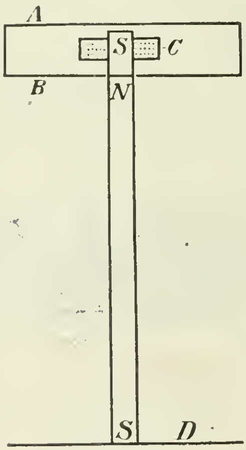


FIG. 17.

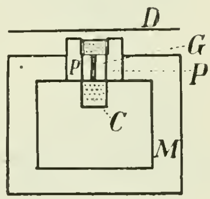


FIG. 18.

inserting another disc at B, loosely surrounding N. Also another disc, D, should be found to make some improvement.

Fig. 18 shows another design which I would suggest for a receiver, where $P\,P$ are soft iron pole pieces, G an air gap, M a permanent magnet and D a diaphragm. It works in essentially the same way, as also does the form suggested in *Fig. 19*, where M is the permanent magnet, C the coil and D the diaphragm.

It was mentioned above that the diaphragm does not move appreciably. Lord Rayleigh has shown that the amplitude of vibration of air particles need not be as much as

10^{-8} centimeters to produce sound. If we take the pull of a magnet on a diaphragm as 10 grams, this makes the energy expended in making the sound to be of the order of 10^{-11} joules. As a good galvanometer can be affected by an amount of energy of the order of 10^{-13} joules, there is still room for some improvement in the telephone receiver.

As regards telegraphic receivers, the principles which I have laid down above cover the main points, I believe, and as the paper is already pretty long, I will only refer to one or two details. As regards the line, the size of the line is governed practically by mechanical considerations, for to stand sleet storms we must have strong wire, and such wire will always

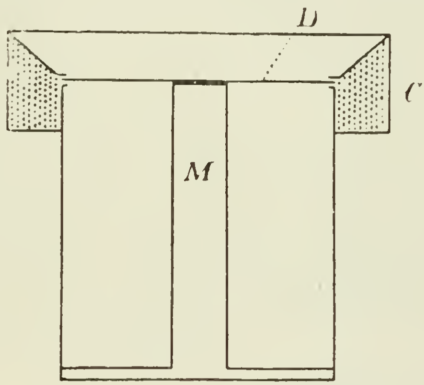


FIG. 19.

have ample conductivity for all practical purposes for all distances, even from San Francisco to New York, for it is doubtful if wire less than No. 8 B and S should be used for telegraphic purposes between places where a breakdown of wires would be of much importance. A line of this size, 3,000 miles long, would, if of copper, have a resistance of say 8,000 ohms, and if we used up 100 volts in the line and 50 in the receiving instrument we would have nearly half a watt to work the receiver, which is more than ample.

The rule generally given for the voltage to be used upon the instrument is that it should equal that used up elsewhere, but I do not consider that practical, and it seems to

me that, under the conditions, if we have much leakage (which is good for some cases, but very bad for the writer's sine curve system), we should increase the voltage till the loss of voltage through increased leakage conductance drop equalled the increase of available voltage available at the receiving end. But for long-distance work, where we can keep the insulation reasonably high, or for all short-distance high-speed work we should use the system described by the writer in the *Electrical World*, September 15, 1899. To quote: "It does not seem to have been generally noted that the sine curve is a necessity for efficient telegraphy. In January, 1891, I designed and experimented upon the system of multiplex telegraphy (by resonant circuits) which Dr. Pupin has recently rediscovered, and noticed this fact. As a result a method was devised by which the operator did not make or break the line circuit with his key, but put in circuit a device which automatically sent out sine waves into the line." This method has since been adopted, with modifications, by several other workers and I understand with quite good results, especially in high-speed work, and I think that there can be little doubt but that the writer's method of producing pure sine waves and sending them out on the line has come to stay, though the original crude method used by me for accomplishing this has been superseded by better appliances.

But when we come to receivers we see that, under practical conditions, apparatus of Class II is the best, and we can devise such very simply by following the rules laid down. It all depends upon how you want your record. Personally, the writer would prefer the following method:

The receiver is that shown in *Fig. 16*. The needle carries a piece of mica, with a slot, vibrating across another slot at right angles to it, and light is thrown down through these slots onto a thin strip of common bromide paper, which is fed along thence into a developing and thence into a fixing bath and finally over hot drying rollers. The light would, of course, come from a powerful source, and with film of fair sensitiveness, I estimate 1,000,000 dots per second. The paper would cost 1 cent per 400 inches of

strip and would be permanent. The paper could all be tested before use and hence there would be no danger of failure.*

If mechanical records were preferred, a balanced microphonic contact could be used.

It is believed that for long lines, between important points, a combination of the writer's method of generating sine waves by a separate device, and using them for signalling, instead of making or breaking the line circuit with a key, together with the receiver shown in *Fig. 16*, and the photographic method of receiving, described above, will give the best results. If multiplex working is desired, then the writer's method of using resonant circuits, devised for the Pennsylvania Railroad in January, 1891, and experimentally tried, with the kind permission of Mr. William Stanley, in his laboratory at Pittsfield, during the spring of that year, will also be found of use.

The questions of the best conditions for rapid work, as regards the line; the best voltage to use; the best kind of insulators and best construction of line are of extreme interest, as also are the questions connected with cable working. But the paper is already sufficiently long, and the discussion of these matters must be reserved for another time.

Stated Meeting, held June 20, 1900.

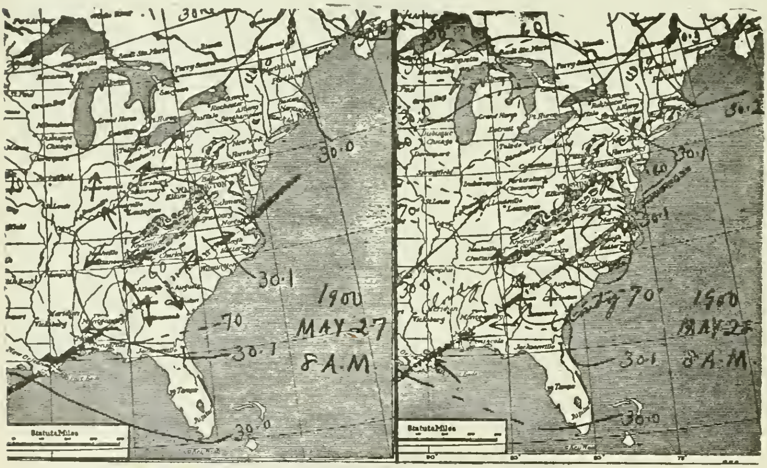
The SOLAR ECLIPSE of MAY 28, 1900.

The following notes of observations of the recent solar eclipse made by members of the Institute were presented at the stated meeting of June 20th.

Mr. H. M. Watts, who devoted his time to a presentation of a few of the meteorological facts connected with the eclipse, began by calling attention to the general weather conditions which prevailed on the morning of the eclipse and the day previous, which were made clear by the

* This lecture was delivered before the publication of the method of Messrs. Pollak and Virag.

projection of two weather maps (8 A.M., May 27th, and 8 A.M., May 28th) on the screen. Mr. Watts called attention to the remarkable positiveness and accuracy of the Monday morning forecast of Prof. Willis L. Moore, of the Weather Bureau, made twenty-four hours in advance, which he ascribed to Professor Moore's expert ability in the balancing of weather probabilities, as the conditions were really such as to make so positive a forecast for the eclipse conditions as Professor Moore sent out on Sunday morning at 10 o'clock a very difficult problem. Mr. Watts explained the weather maps at some length and showed that on the morning



Weather conditions on the morning before and the morning of the eclipse, showing the anti-cyclone (area of high barometer) overlaying the path of the eclipse shadow.

ing of the eclipse over the entire eclipse tract there was an area of high pressure very little above the normal of 30 inches, which insured remarkable steadiness and a general even circulation of the air from New Orleans to Norfolk. There were no clouds along the entire line of totality in the United States, the weather on Monday being as Professor Moore predicted on Sunday, the best "seeing conditions" possible.

Mr. Watts then took up the question of the weather changes that occurred during the eclipse and pointed out

that they were comparatively slight indeed in this eclipse and not as marked as those that have occurred before, or as the general impression is usually the case. Theoretically, the chilling of the moon's shadow should cause a heightening of the pressure and a change in the wind velocity and in its direction of movement. At Norfolk, where Mr. Watts saw the eclipse, there was no change in the wind's direction at all, and but a very slight increase in the velocity during the eclipse. The wind was from the south all the time. As to the temperature changes, the thermometers registering air temperature showed very little change. At 8.23 at Norfolk, at the Weather Bureau office, the dry thermometer was 69·04°; at 8.53, 68·05° (totality); at 8.58, 68·02°, after this slowly rising to the normal for the day. The wet bulb at 8 o'clock was 62·05°, with a relative humidity of 69 per cent.; at 8.48, 60·02°, with a relative humidity of 55; at 8.53, 60·05, with a relative humidity of 56; at 8.58, 61°, with a relative humidity of 57. These changes were hardly appreciable so far as the general air temperature went, but at Virginia Beach there was a more decided fall, the thermometer falling from 69° at 7.45 steadily downward to 59 during totality at 8.55, rising again to 69 at 10 o'clock. The dew also formed at Virginia Beach, and the sea breeze from the east which was blowing early in the morning under the prevailing wind current from the south ceased during the eclipse, the wind shifting slightly between south and southeast, also varying very slightly in velocity, an increase being noted during totality.

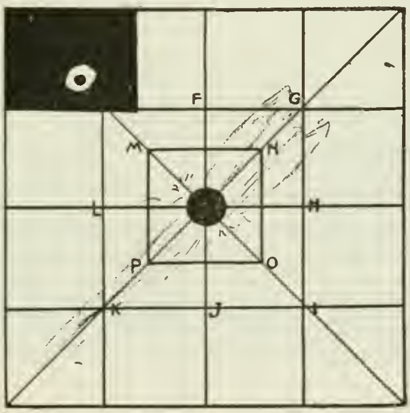
In discussing the slight changes in the air temperature during the eclipse as compared with the general sense of chill reported by so many observers, Mr. Watts reported that he felt no chill on the roof of the Weather Bureau at Norfolk, and attributed the very slight air change there to the fact that Norfolk was a very large city, where the air temperatures vary much more slowly than in the open country. At any event, however, the general air temperatures would never show the marked change which seemed to take place to the observer, and the peculiarity of this phenomenon, which Mr. Watts said had been the subject

of a great deal of discussion, seemed to him very simple, as the great chill reported was due, not necessarily to any unusual falling of the air temperatures, but to the chilling of the skin of the face by the removal of the sunlight. Mr. Watts pointed out that it was well known that the thermometer in the full sunlight would show a temperature varying from 20° to 30° to 40° above the temperatures of thermometers enclosed in shelters which only gave the air temperatures. Hence the temperature of the skin in full sunlight would be much greater than the temperature of the skin with the sunlight cut off, and it was to this physical effect on the superficial layers of the skin that Mr. Watts attributed the sense of extreme chill which, associated with the extraordinary spectacle of the eclipse, through association of ideas became possible of great subjective exaggeration.

Mr. Watts said that he saw no shadow bands at Norfolk, but judged from the various reports that the belief that these were optical illusions was forever dispelled, although no less an authority than Professor Newcomb, up to the time of this eclipse, thought that the shadow bands might have no real existence. The evidence during this eclipse, Mr. Watts said, suggested that they were meteorological phenomena; light effects due to air currents. He read a letter from Prof. Frank L. Bigelow, of the Weather Bureau, who said that, while not prepared to report, observations had been made which would prove very interesting and instructive and had disclosed new phenomena. Mr. A. Lawrence Rotch, of the Blue Hill Observatory, was quoted in a letter saying that while the shadow bands still puzzled him, it must be admitted that they were of atmospheric origin, and Mr. G. W. Pickard, acting for Blue Hill, in a note to Mr. Watts, reporting on the shadow bands as seen at Virginia Beach, wrote as follows:

"As seen by the writer, the bands were at first wavering shimmers of light and shade, very like the reflection of sunlight from the surface of slightly rippled water to a screen. Within a few seconds they became more distinct, with an apparent velocity of 6–12 feet per second toward the south-

west, the bands themselves being at right angles to this direction. They became more and more distinct until the moment of totality, during which no bands were noticed. The bands reappeared almost simultaneously with the third contact, very distinct at first and gradually fading away with the increasing light, identical in appearance with those before totality, save that the distinction was in reverse order. Perhaps the best idea of the wavering motion of the bands can be obtained by walking past a double line of picket fence, noticing the flicker as the relative positions of the pickets and the open spaces between them conflict. The bands were first observed one minute and thirty seconds before totality and lasted about the same length of time afterward."



Drawing of the corona made at Norfolk, contrasted with small photograph made at Cape Charles, Va.

Mr. Watts, in conclusion, presented a diagram of the appearance of the corona, drawn by him at the time of the eclipse, which showed a broad flame-like appearance for the upper equatorial extension and a more pointed form for the lower equatorial extension, the former stretching about three diameters and the latter four.

Mr. A. E. Kennelly:—Mr. J. M. Justice and I went to Virginia Beach* to observe the eclipse as sight-seers and

*Near Norfolk, Va.

amateurs. We took with us a copying camera with 6 feet of extension, and 8 inches by 10 inches double coated and backed Seed's plates. We arrived at Virginia Beach on Sunday the 27th ult. Early on the morning of the 28th we selected a position on a small sand dune about 30 feet above sea level, on the western side of the railroad switch at the northern vertex of the railroad delta, which is about half a mile below the Princess Ann Hotel. Here we set up a rough platform at about 45° elevation for the camera to face the sun at totality. This we fitted with the back combination of a 3 inch aperture Dallmeyer lens of 49 inches

Camera and oriented sheet at Virginia Beach, near Norfolk, Va.

focal length. Being used without a diaphragm, this lens gave us a focal length divided by aperture of $f = 16{\cdot}3$, approximately. A smaller camera 6·5 inches by 8·5 inches on a tripod was also used, of 10 inches focal length and $f = 16$.

A metronome was employed and timed to give sixty beats per minute. By its aid we were enabled to count out the period of totality. A stereopticon sheet 9 feet square was oriented with the aid of a sling compass and spread horizontally on the sand, fastened to stakes at the four corners.

We were joined by Professor and Mrs. C. F. Himes, Miss Mary M. Himes and Miss Anna M. Himes, who assisted us in making our observations.

The sky was clear and cloudless until about fifteen minutes before totality, when a few light cirrus clouds appeared some 15° above the northern horizon. Otherwise the sky remained cloudless throughout the eclipse.

After the first contact no noticeable effects were observed until about thirty minutes before totality, when the diminishing sunlight began to produce a reduction in the apparent warmth of the body, and the color values of the landscape commenced to change from the bright tints of full daylight to deeper and more sombre tints, differing perceptibly, however, from those which would accompany the obscuration of the sun to a corresponding extent by clouds. The progress of the moon's shadow across the sun was followed, both upon the ground glass of the camera and also with the aid of smoked glasses.

A watch was kept on the sheet for shadow bands, but none were observed until about thirty seconds before totality, when they became distinctly visible; the general illumination was then quite low. They appeared like ripple marks in rapid agitation. They formed ripples like undulating dark cords on the general light surface of the sheet. They were not so sharply defined, either in the direction of their wave crests or in the spacing between successive waves, as to make accurate observations possible, but, in general, the waves had their crest lines parallel to each other. Each crest line was not a straight line, but a line undulatory about a mean line which might be regarded as straight. These mean crest lines were diagonal to the sheet, or northwest to southeast, while the direction of the motion seemed perpendicular to the direction of the crests, or southwest to northeast, and progressing from the southwest to the northeast. The distance between successive waves, or the wave length, appeared to be from 1 foot to 18 inches, and there appeared to be about six waves passing any point in each second, or what would correspond to a linear velocity of 6 to 9 feet per second. The contours

were neither sufficiently sharp, nor the spacing sufficiently regular, to warrant any precise statement, however, as to the velocity. The waves seemed complex and composite, and the spaces between main crests were usually filled with fainter ripplings. The appearance of these shadow bands was similar in character to that which is produced by the falling of sunlight upon a bright floor after passing immediately over a highly heated register. The bands continued visible until the arrival of totality, when they were completely lost in the darkness.

The onset of totality was marked by the appearance of a deep blue-black gloom almost cloud-like in its appearance, which appeared to settle steadily upon the landscape, but no moving shadow of the moon could be seen from our point of observation.

There was a very faint sea breeze; that is to say, a very faint easterly breeze during the interval between first contact and totality, accompanied by a general light southerly breeze. About the period of totality the sea breeze died away, but the smoke from chimneys showed that the light southerly breeze still persisted.

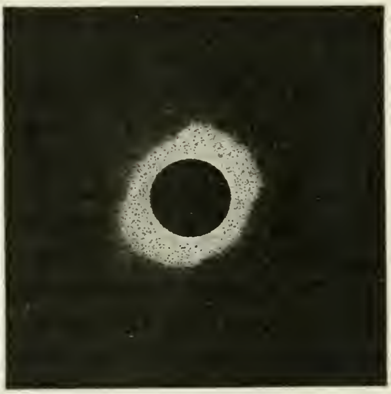
The moment at which totality commenced appeared to be sharply defined to observers watching either the sheet or the landscape, owing to the sudden loss of light. At the same instant the corona leaped into view. It stretched out, as judged by the naked eye, to a distance of about 2·5 diameters from the moon, both at the eastern and at the western limb. The contrast of the black moon against the corona was very vivid. The general illumination at this time was very feeble, but it was possible to read ordinary print without difficulty. Over the sea on the eastern horizon was a horizontal rosy-red strip of sky 2° or 3° in height, into which the moon's shadow did not enter, and from which some diffused light was scattered over the general landscape. Mercury and Venus were distinctly visible.

The corona had a pale silvery sheen like moonlight shining through gossamer threads. It was colorless and resembled in general dimensions a capital A, set on its side thus, ⋖, with the moon on the cross-bar.

The first photograph was taken five seconds after the commencement of totality with an exposure by metronome of one-half of a second. The second photograph was taken fifteen seconds after the commencement of totality with an exposure by metronome of three-quarters of a second. These two pictures are here reproduced. After the eclipse was over an improvised dark-room was prepared, the plates were removed from the plate holders, marked on their top sides and packed in a separate box.

Just as the sun's edge flashed out suddenly over the moon's limb, marking the end of totality, the eye being sensitive from the preceding darkness, it became apparent,

Photograph No. 1. 5 seconds after commencement of totality. Exposure, ½ second.



Photograph No. 2. 15 seconds after commencement of totality. Exposure, ¾ second.

without the aid of a telescope, that the effulgent edge was not a geometrical segment of a circle uncovered by a circle, but a series of bright dots uniting into a circular segment.

Immediately after totality shadow bands were again observed for about thirty seconds. They appeared somewhat more distinct than those which preceded totality. The general direction of the wave crest lines appeared to be about the same as before totality, but the direction of progression seemed to have reversed or to be from northeast to southwest. This apparent reversal of the progression may have been only imaginary, although it was the general impression of the observers.

Dew was deposited upon the external wooden surface of the camera during the eclipse, and was also deposited upon grass and other objects in the vicinity.

The plates were developed by Mr. Justice in pyro solution. The diameter of the moon's image on these plates is 0·42 inch. Notes of these observations were written out shortly after the eclipse. The following are also notes independently written out, very shortly after the eclipse, by Miss Anna M. Himes, concerning the shadow bands:

"(1) They were visible for about equal times both before and after totality.

"(2) They appeared brighter after totality, which was most likely due to the greater sensitiveness of the eye.

"(3) They were long waves with shorter waves superimposed.

"(4) The direction of the waves was the same both before and after totality.

"(5) The waves advanced in opposite directions before and after totality."

PROF. CHAS. F. HIMES remarked that to him, as one of the members of the government expedition organized and so efficiently conducted by Prof. Henry Morton, then Secretary of the Franklin Institute, to observe and photograph the total eclipse of 1869, comparisons of the eclipse of this year with that of 1869 naturally suggested themselves, as well as other incidents in this connection that might not be without interest, at least, to members of the Institute. First he would say that the remark at the close of the report of the section stationed at Ottumwa, Ia., made by him, that the experience gained would be of service in a future observation, did not apply, except in a very general way, after the lapse of thirty years, as the points of interest had changed, entirely new problems had arisen to which instrumental aids had had to adapt themselves. Then the spectroscope was a comparatively new introduction and did settle some questions. The experience of that date, however, that did service in force was the necessarily unsatisfying character, at that time, of the observation of the phenomenon as a whole, and the resolution, if the opportunity should again

offer, not to be controlled, at least during totality, by the requirements and responsibility of special observations.

It was a matter of congratulation, therefore, soon to discover that Dr. Kennelly and Mr. Justice, with whom it was his good fortune in many ways to be associated, were so completely prepared at all points that they were amply able to manage the observations they had proposed for themselves without necessity of offer of assistance from him, at least during totality. In 1869 wet-collodion was dominant, with its requirement of well-constructed dark-room, all the impedimenta of baths, solutions, etc., as well as the details of preparation and development of plates on the ground. It was at best slow, rigid and unaccommodating. Those in the dark-room (Mr. John C. Browne and Mr. W. J. Baker) had to be satisfied with the merest glimpse of totality stolen from the door of the dark-room. As there were no instantaneous shutters then, so common and mechanically perfect to-day, it was fortunate that the Institute had among its members the scientific, ingenious and skilled Joseph Zentmayer, always ready to contribute of his valuable time and peculiar ability to assist in purely scientific work. He devised and made shutters for the cameras attached to the several telescopes, with which exposures could be made for small fractions of a second during the partial phases, and time-exposures during totality, and withal connected electrically with a chronograph upon which the times of exposure were recorded by the click of the exposure slide. Other astronomical as well as photographic demands were equally well met by him, and a modified Huyghenian eye-piece afforded images of the sun about 2 inches in diameter. The expedition was divided into three sections, one each at Burlington, Mt. Pleasant and Ottumwa, Ia. Weeks were spent in experimenting and practicing on a vacant lot in West Philadelphia, and the parties set out ten days before the date of the eclipse for their several points of observation. This very general statement will suffice to show the relation of the Franklin Institute to the observation of the eclipse of 1869. Full details may be found in the reports published at the time

in the *Journal* of the Institute, and also separately by the government. The latter, with larger liberality than at present, without the expenses of the Spanish War and expansion, appropriated $5,000 for the expedition, and the railroad companies, under the inspiration of Mr. Thomas Scott, then President of the Pennsylvania Railroad, supplemented this provision of the government by free transportation of the observers and their apparatus in a new first-class car, specially fitted up for their accommodation, carried without change, by way of the bridge at Burlington to the several points.

This was not so small a matter at that time, when through trains were not run beyond the Mississippi. The money value of this favor of the railroads was estimated at $1,500. There was, of course, the usual anxiety about the weather, without the comforting assurances from our present reliable Weather Bureau alluded to and with rains and violent thunder storms up to the very day of the eclipse. But the hour of the eclipse found a perfectly cloudless and bright sky and all adjustments and preparations complete. But after everything has been thought of and done in such cases, there is always room for a residuum of one or perhaps several minor omissions that may imperil success and neutralize the most elaborate preparations. Nothing more than such an observation as this serves to impress the fact that nature does not recognize the terms "trifling" and "minor," frequently applied to any of her conditions. The more elaborate the preparations, the more points at which disturbing factors may enter. The chronograph seemed to be in good working condition. It was also to be used by Prof. Stephen Alexander, of Princeton, who had observed several previous total eclipses, and, accompanied by General Halsted, who had recently erected a fine observatory for Princeton College, was at the same point. As it was in the hands principally of volunteer assistants, there seemed to be big possibility that at the critical moment something unexpected might happen. Arrangements were therefore made for timing the exposures independently of the chronograph, by means of a chronometer, the sharp click of the exposure

slide favoring this. It proved fortunate, as the chronographic record became defective in a very unexpected way. Professor Alexander sat beside the seconds-tapper and, as had been agreed, quietly slipped his hand over to use the key to interpolate the time of an observation he was about to make upon the fillet, between the marks of the seconds, and the tapper, thinking the professor was about to assume his occupation, stopped tapping, and the record of seconds on the fillet ceased. The psychological conditions, though not without their humorous side, are not to be left altogether out of account. As totality approached, Mr. Zentmayer was at the camera. He had scientific training, and was as cool and self-controlled as most of us. He had just made the happy exposure which captured Bailey's beads. Then, in the darkness that suddenly enveloped the whole scene, as the corona burst forth, with its attendant appearances, both gazed at it. Professor Himes, not hearing the click of the slide announcing exposure, turned to Mr. Zentmayer to see him standing, with arms extended, gazing fixedly at the phenomenon, apparently entirely oblivious that exposures were to be made, and that the time was counted by seconds. A word to him broke the spell, and he turned hurriedly to the camera. Still no click telling of exposure came. On inquiry, Mr. Zentmayer replied that it was too dark to make the adjustment of the exposure slide required by the feebly actinic corona. The lantern, very thoughtfully provided for such a contingency, hung above his head, but unlighted. The minute thus lost was long enough to permit a whole train of thoughts and feelings of mingled disappointment and mortification that through an oversight so apparently trifling all should have come to naught. The three negatives of totality secured in the remaining time, the longest exposure being sixteen seconds, were regarded as very successful for that time, the one last taken being especially interesting on account of the suggestion of the corona which it gave.

Professor Schellen, in his work on the Sun, and in that on Spectrum Analysis, gave it a special place of honor, and others make particular mention of it. It is easily seen from

the positives from these, thrown upon the screen, how much less they tell than the negatives of to-day with the more sensitive and accommodating dry plate. Attention was especially directed to the slide of Bailey's beads, the merest points of light left by the ragged edge of the moon, yet sufficient to restrain the outburst of those grand features that separate totality infinitely from all partial phases, and make it an incomparably grand, unique, indescribable phenomenon. This seemed to take a deep hold on the observers of that day. An effort was made by Mr. Zentmayer to express it by means of a mechanical slide. As thrown upon the screen it first presented a photograph of the sun of that day with some well-defined spots; a circular disc representing the moon gradually passed over it until the last faint line was cut up by the ragged edge, when corona and the attendant red prominences surrounding the black moon burst forth suddenly and unexpectedly. It is the grandeur and suddenness of this display that many who have never witnessed it fail entirely to comprehend. In this connection he had hesitated to compare the eclipse of this year with that of '69. It was this general view which he desired to hold himself perfectly free to observe. But a second view of the grandest phenomenon may reduce its impressiveness and disillusionize an observer; but the general reports of the eclipse just passed, and comparison with others of recent years, emboldened him to say, that whilst it could not fail to impress permanently the mind and heart of every one privileged to witness it, yet in some of its features it fell notably behind that of 1869. The red prominences, or protuberances, were not as numerous nor as large. They were a matter of general comment and remark, even as seen by the unaided eye in 1869. The corona was not of the same shape, as can be seen from the slides of the recent eclipse and the totality slide of 1869, which, although not photographic, was from the most generally accepted drawings. Neither did it have the same extent, nor manifest to the unaided eye the texture or movement of the former one. The sudden darkness of totality did not seem as intense, and, as a consequence, the stars did not seem to spring out with the same brightness,

and the apparent reduction of the extent of the corona and absence of character may be in part accounted for by this fact. Nothing of all this, said by way of comparison, is to be understood as in any degree detracting from the gratification of witnessing this grand exceptional phenomenon under circumstances so favorable. Others were present who took part in the former observations, from whom it would be a pleasure to hear. As to the "shadow bands," there were so many other unmistakable and indisputable points to occupy the very limited time, and he was so skeptical in regard to them, that, unless provision had been as carefully made by Doctor Kennelly to look for them, he would have neglected them entirely; as it was, he must now add his testimony to that of the others as to their existence, and suggest that they may repay future more careful observation and study.

MR. ARTHUR T. COLLINS:—Our party consisted of Prof. G. A. Hoadley, Mr. Chas. U. Bedell, Professor Price and myself. We located at Kelford, N. C., which is exactly on the central line of the shadow path. The objects we had in view were threefold, namely, photographing the corona, measurement of the position of the coronal line, and observation of shadow bands. Professor Hoadley and Mr. Bedell obtained six negatives of corona and prominences, some of them quite clearly showing coronal streams and two or three prominences of the horn variety, one being about 25,000 miles in height. Their instrument consisted of a 3-inch telescope objective, mounted in a camera box, the length of which was equal to the focal length of the lens. This was mounted on a polar axis and operated by screws in Decl. and R.A., the instrument being allowed to rest during exposure.

My part of the work was to measure the position of the coronal line. In order to do this I used a spectroscope, containing one compound Rutherfurd prism by Brashear, mounted equatorially and driven by hand. The telescope was moved on same mounting

$$\frac{f}{a}=13.$$

I used a radial slit set at point of second contact. At the moment of totality the dark lines turned to bright lines for about one and a half seconds in time. This is due, as is well known, to obtaining at that point the spectrum of the chromosphere, which contains the elements in the form of glowing gas, and which ordinarily produces the dark-line spectrum. I noted also that the bright lines of the chromosphere were of quite different lengths, most of them being only dots, while others appeared to be $\frac{1}{4}$ inch long, showing that different elements rose to different heights above the surface of the sun.

Previous to making my observations the pointer in the micrometer was set on the line γ 5317 (1474 K). This line was bright during the flash in common with others and faded out when the moon had passed over the chromosphere. Then I saw the coronal line take its position just above or toward the violet. The pointer was moved up and the measurement taken. I make the new position to be γ 5304, and believe this is near the true place. It seemed that all the lines in the field of the spectroscope flashed bright, but the time was so short that only a guess as to the truth of this could be obtained.

We had hoped to photograph the shadow bands, but found them quite too fleeting and indistinct to even attempt it; but on their second appearance we laid dowel pins, painted black, on the sheet, to indicate their direction and distance apart, and photographed these together with a measure in feet and inches, also a north and south line. We found the shadow bands to be $1\frac{1}{2}$ inches wide and from 7 to 9 inches apart, the crest of the wave or band being irregular in shape, having the appearance of ripples on water caused by wind and moving at the rate of probably 10 feet per second, the crest of the wave moving in the direction of the path of the eclipse at both appearances.

MR. FREDERIC E. IVES:—My son and I went to Norfolk, and from there to Virginia Beach, to see the eclipse. We took with us a 3-inch telescope, two spy glasses, opera glasses, colored glasses, a spectroscope and a polariscope, but no photographic apparatus. We thought it would be a

waste of time to make small photographs with ordinary camera or small telescope when some of the eclipse expeditions were so much better equipped for such work.

I had thought of attempting to make a Kromskop color photograph, which, if it could be successfully accomplished, would be extremely interesting, and have some real value as a record, provided that the red prominences were as large and striking in appearance as they have been on some occasions; but in order to make such a photograph, it would be necessary to employ a clock-driven equatorial mount, which I could not readily obtain when I wanted it, and this fact and the knowledge that the prominences were not likely to be very striking at a period of sunspot minimum, led me to give up the undertaking.

We missed the shadow bands, and observed nothing but the waning light and relief from the sun's heat until almost the moment of totality, when my son, who was at the telescope, remarked that he had a beautiful view of the Bailey's beads. At the moment of totality he threw aside the dark glass and examined the prominences and the structure of the corona.

I was using the spectroscope at the commencement of totality, and after seeing the bright-line spectrum, viewed the eclipse through an opera glass, looking particularly for the prominences, which, however, were so much smaller than I expected, that I did not then see them at all, but noticed particularly the form and pearly effect of the coronal light and the appearance of what we called, for want of a better name, "the lines of force," simulating the arrangement of iron filings about the poles of a magnet. My son reported a most beautiful wispy structure visible in the telescope, and small prominences which were not crimson, but suggestive of bits of incandescent wire.

We then exchanged places, and what impressed me most in the telescopic view was the resemblance of the prominences to the color of burnished copper reflecting sunlight. Other observers have since stated that they did not appear to them to be crimson or red, but a sort of brick red or pink. They were not sufficiently large and striking

to have shown to advantage in the Kromskop in a view showing the entire corona, and my decision not to attempt such a photograph was therefore justified. The two largest prominences, which were quite near together, looked like loops of fine wire (we were using a low-power eyepiece), and we both noticed a peculiarity in the focussing which in itself would have indicated to an optician that the light was made up of widely separated bright lines or bands in the spectrum.

The total phase passed all too quickly, and we noticed that the corona remained visible for some seconds. We noted the brilliance of Mercury, and the orange color near the horizon, and that the light appeared very much stronger than that of the brightest moonlight, apparently quite sufficient for reading fine print; but we made no important observations, and did not go there expecting to make any.

MR. JOHN CARBUTT:—It would be presumptuous in me to try to add anything to what Professor Himes and the gentlemen preceding him have already said on the scientific aspect of the late eclipse, but I will make a few remarks on the use of photography in eclipse observations. Thirty years has brought quite a change in processes used. In 1869 I was invited by Prof. Henry Morton, the then Secretary of the Franklin Institute, to accompany his section of the observers organized by the Franklin Institute to Mount Pleasant, Ia. At that date I was residing in Chicago. I took with me my wet-collodion outfit; our location was in the Fair grounds, a room in one of the buildings was used as a dark-room in which I prepared and developed the plates as fast as exposed, Mr. Ranger, of Indianapolis, with Mr. Clifford, of Philadelphia, carrying the plates to Professor Morton, who was assisted at the telescope by Mr. E. L. Wilson and James Cremer. Of course, I saw nothing of the beginning or ending of the eclipse, but during totality I was called out to see it. I must leave you to imagine my sensations when, after entering the dark-room with bright sunlight outside, I emerged into what by contrast was almost Cimmerian darkness. The men around the telescope were barely discernible. I may here say that

I have the camera and amplifying lens made by the late Mr. Zentmayer, used at Mount Pleasant, which was presented to me by Professor Morton.

After the eclipse was over I made a stereoscopic negative of the party, an enlarged copy of which I here present to the Institute, also an enlarged print from the negative of partial phase of the late eclipse I made at Wayne Junction while the sky was full of clouds. The sun's image on the negative is 5 millimeters in diameter, and was made on a triple-coated plate, backed, with the back combination of a euryscope lens of 22 inches focus, stop F/44, Prosch shutter, speed about $\frac{1}{25}$ of a second. Astronomers photographing the late eclipse have availed themselves of the improved methods in preparing gelatine dry plates, and as a dry plate maker, I was called on to make plates of various speeds, from single-coated slow emulsion to double and triple-coated plates with different speeds of emulsion; I also made for the Smithsonian Institute circular celluloid plates 16 inches in diameter, of $\frac{1}{16}$ inch thick. All the glass plates were backed with black backing and prevented halation entirely.

MR. S. A. TATNALL:—What has already been said by those who have just spoken corresponds so nearly with the impressions which the eclipse made on me, that I fear I can add very little of interest. I have not heard, however, any expression as to the degree of darkness during totality, which I found to be rather difficult to judge. This being my first experience with total eclipses, I have little to compare with, but it seemed to me to be somewhat darker than full moon. I doubt if I could have read fine print of a newspaper.

The negative from which the slide was made was taken at Norfolk, Va., with the back combination of an 8 x 10 Leclair lens, having a focal length of about 24 inches and aperture of 1½ inches. I did not use any stops, and exposed one second on a Cramer Crown plate, backed.

The plate was developed with metol, weakened with water and a liberal quantity of bromide added.

Mining and Metallurgical Section.

Stated Meeting, held Wednesday, December 14, 1899

SOME PROBLEMS IN DEEP COAL MINING.

By H. M. Chance, Philadelphia, Pa.

In mining coal seams lying at considerable depth beneath the surface the engineer is confronted by difficulties not present in shallow mining. Modern American mining practice requires large output as the first prerequisite of a successful mining operation, for without this it is impossible to mine at a cost per ton low enough to compete with the more shallow mines.

As depth is reached in any coal-field the quantity of explosive gases given off by the coal increases rapidly, requiring a larger quantity of air to properly ventilate the workings. This is the problem of greatest importance, how to supply adequate ventilation, for without abundant ventilation it is impossible to open and work enough rooms or chambers to produce the desired output.

As the depth increases, the roof of all coal-beds, being subjected to greater pressure from the increasing mass of overlying rocks, is more likely to fail, and in deep mines we generally have what the miners call a "bad roof," although the roof may really be a very good one but unable to stand the enormous pressure which comes upon it.

A "bad roof" means increased cost of working, for not only does the roof break and fall in the rooms or working places, but on the main haulage roads and airways as well, involving heavy expenditures for timbering, for the renewal of timber, and for labor in clearing away such roof-falls.

Again, as depth is gained, the risk of closure of the workings by "squeezing" or crushing of the pillars of coal left to support the roof, rapidly increases with the increasing weight of the overlying rocks.

The three important problems presented by deep coal mining then are:

(1) To provide ample ventilation, which may be increased as the area of the workings enlarges.

(2) To reduce the cost of maintenance due to roof-falls, especially roof-falls on gangways and airways.

(3) To limit the possible damage from "squeezing" and to prevent "squeezes" from closing the main haulage roads and airways.

Several systems have been devised and used for providing adequate ventilation under such circumstances (among which may be noted the "Three Entry" system which is largely used), but they all are open to serious objections.

These systems generally use the main haulage roads as intakes for the ventilating current, and these must then be driven very wide to give the necessary cross-sectional area of airway, thus increasing the cost of timbering, and risk of damage from roof-falls. To secure additional area the return airways are either driven double (as in the "Three Entry" system) or of large cross-sectional area, which is objectionable, not perhaps because of increased roof-falls, but because of increased first cost, and a slower rate of developing new territory.

The risk of damage to main roads and airways by "squeezing" is now generally guarded against by leaving a thick pillar of coal separating these from the working places, this pillar being broken only by necessary openings for roads or airways.

It is evident from the outset that the only way to reduce the cost of maintenance of the main haulage roads, and save timber, and the delays and accidents incident to roof-falls is to drive these haulage roads as narrow as possible. It often happens that a gangway 9 or 10 feet wide may require no timbering, the roof standing for years, while if driven 14 feet wide it might require heavy timbering throughout or give constant trouble from roof-falls.

Now, if the main haulage roads are driven narrower to save timbering, cost of maintenance, and delays and accidents from roof-fall, it is evident that they cannot be used

as the main intakes for ventilation, as they will be too small to carry the increasing volume of air required as the workings extend to long distances from the shaft.

The system described below which has been devised to overcome these difficulties should effect a considerable economy in timber, maintenance, operation and first cost of dead work, in addition to providing facilities for efficient ventilation, and reducing the risk of accidents from roof-falls, transportation and explosions. I will attempt only a description of the principal features of this mining method, the details of application of course varying with the conditions present.

The main haulage road (with its airways), whether this be a water-level gangway, a slope to the dip, a plane to the rise, or a face entry driven across the dip, is driven ahead into the new territory, as in present practice, and the water-level gangways or butt entries (each with its airway), from which the chambers or rooms are to be opened, are located at intervals of 300, 400, 600 feet or more as desired.

This main haulage road and airway are driven as narrow as possible to prevent failure of the roof and save timber, a good pillar of coal being left between, broken at intervals by small cross-cuts, such as are essential for ventilation while they are being driven.

Upon driving the desired distance, a water-level gangway (or butt entry) and airway is opened to right and left, and from these, on each side, two rooms or chambers are opened and work back to the last gangway. These rooms or chambers are driven parallel to the main road and airway, an unbroken pillar of 30, 40 or 60 feet separating the first room from the road or airway and a pillar of good thickness separating the two rooms on each side. When these rooms are worked back to the last gangway and holed through, we have, in addition to the first two openings driven, that is, the main road and airway, four wide parallel roads or airways. The outside room on each side is used as a return airway and the inside rooms as intakes, and the original main road and airway are also used as intakes.

The inside rooms may be driven 16 or 18 feet wide and the outside rooms 22 to 28 feet wide.

The inside rooms, in addition to their use as intake airways, are also used as manways or travelling ways, so that miners need travel neither along the haulage road nor in the return airways.

A thick barrier pillar of coal is left beyond the outside rooms, separating these from the working places to protect these airways and the haulage road from damage by squeezing.

This system gives four straight and continuous intakes and two large return airways throughout the length of the main haulage road. The mine workings on each lift or gangway are ventilated by a separate split taken in through the gangway and workings, and returned through the airway to the main return.

The two intake chambers being used as travelling ways may require center props. The main haulage road will require little if any timbering unless the roof be very weak.

In the absence of a diagram and to simplify the description as given above, the method may be described as a modification of that in ordinary use where a barrier pillar is left on each side of the main haulage road and airway, to separate these from the rooms or working places, this modification consisting of transposing a pair of rooms on each side of the barrier pillar from a position outside this pillar to a position inside the pillar, and locating these pillars a corresponding distance away from the main haulage road.

BOOK NOTICES.

Hydraulic Power Engineering: A practical manual on the concentration and transmission of power by hydraulic machinery. By G. Croydon Marks. London: Crosby Lockwood & Son. New York: D. Van Nostrand Company. 1900. 8vo, pp. 360. (Price, $3.50.)

The present work is intended by the author as an aid to engineers engaged in the designing and construction of works and machinery for the utilization of water for power transmission. The author disclaims the idea that his work deals adequately with all the problems arising in the practice of hydraulic engineering, but he has made a satisfactory attempt to present in intelligible form a description and discussion of the essential features of the subject as they will be called into requisition by the needs of the hydraulic engineer. W.

Leçons d'Électrotechnique Generale, professées a l'Ecole Superieure d'Électricité. Par P. Janet, Directeur du Laboratoire Central et de l'École Superieure d'Électricité. (Large 8vo, pp. ix-608, with 307 figures) Paris: Librarie Gauthier-Villars. 1900. (Price, 20 francs.)

This volume may be considered as a supplement to the same author's *Premiers principes de l'Électricité industrielle*, previously noticed in the *Journal*. It is an elaboration of the course of instruction in electrotechnics followed in the École Superieure d'Électricité in Paris. W.

Hand-book of Practical Hygiene. By D. H. Bergey, A.M., M.D., First Assistant, Laboratory of Hygiene, University of Pennsylvania, Philadelphia, Pa. Easton, Pa.: The Chemical Publishing Company. 1899. 8vo, pp. 164. (Price, $1.50.)

This work has been prepared with the view of affording the student a convenient hand-book to serve as a guide in practical laboratory work in the sanitary examination of air, water, soils, the principal food products, and in testing the ventilation of buildings. The five chapter heads treat of the subjects above named and in the order given

The analytical methods given are generally the more simple and convenient ones, and the instructions given are clear and concise. The book should prove extremely useful as a laboratory guide. W.

The Chemistry of Soils and Fertilizers. By Harry Snyder, B.S., Professor of Agricultural Chemistry, University of Minnesota. Easton, Pa.: The Chemical Publishing Company. 1899. 12mo, pp. ix–277. (Price, $1.50.)

This is an elaboration in book form of the course of instruction given by the author to the classes of young men attending the University of Minnesota, who intend to become farmers, and who need some knowledge of the chemical and physical properties of soils, of the nature of plant growth and nourishment, the exhaustion of soils, the conservation of soil fertility by the proper selection and use of fertilizers, etc., etc.

These subjects are all treated of in this hand-book in a plain, comprehensible way. Practical agriculturists generally should find it helpful.

W.

Commercial Organic Analysis. By Alfred H. Allen, F.I.C., F.C.S. Third Edition, with Revisions and Addenda by the Author and Henry Leffmann, M.A., M.D. Vol. I and Vol. II. Philadelphia: P. Blakiston's Son & Co. 1898.

This revised and augmented edition of Allen's unique work is certain to meet with a hearty reception by the analytical fraternity. It is several years since the second edition of the work has been exhausted, but no other book as comprehensive in scope and accurate in detail has yet appeared to take its place. A mere reprint even would have been welcomed by many chemists. While this first volume of the new edition has not, perhaps, been revised as thoroughly as it might have been had the American editor been given a freer hand and ampler time, it must be conceded that the joint endeavors of the

author and editor have gone very far towards bringing the work up to date. The first volume is now devoted to the general analytical operations, the alcohols and their neutral derivatives, the sugars, starches and vegetable acids. On the whole, these subjects are treated very satisfactorily, many of the additions made by Dr. Leffmann being of special interest to American chemists.

The author and Dr. Leffmann have also collaborated in the preparation of the second volume, of which the second part has just been issued. Its revision appears more thorough and complete than that of Vol. I; the American editor has added largely to the sections on hydrocarbons, petroleum and coal-tar products, and asphalt—the last-named subject being treated in a masterly manner—while Mr. Allen has given special attention to the description of the tests of phenols and allied subjects. The new classification of the hydrocarbons, the addition of certain technological summaries, such as those on acetylene and coke-oven tars, and of tables of comparison of density and temperature scales are worthy of special mention. H. F. K.

Franklin Institute.

[*Proceedings of the stated meeting held Wednesday, June 20, 1900.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 20, 1900.

MR. JOHN BIRKINBINE, President, in the chair.

Present, 135 members and visitors.

Additions to membership since last report, 23.

Mr. Arthur M. Greene, Jr., Dr. Joseph W. Richards and Mr. Henrik V. Loss were authorized to act as delegates of the Institute to the various scientific congresses to be held in connection with the Paris Exposition.

The President announced that arrangements had been made for the reception of the reports of various members of the Institute who had made observations of the recent solar eclipse (of May 28th).

Dr. A. E. Kennelly, Mr. H. M. Watts, Dr. Chas. F. Himes, Mr. F. E. Ives, and others, thereupon presented accounts of their respective observations. (The full account of the remarks of these observers appears elsewhere in this impression of the *Journal*.)

Dr. Wm. H. Greene, who was announced on the program for a paper on "Prismatic Lighting for the Illumination of Dark Interiors," being prevented from attending the meeting, his paper was read by Mr. Chas. C. Hicks. The paper was freely discussed, and the subject was referred to the Committee on Science and the Arts for investigation and report.

The Secretary exhibited commercial specimens of sheet steel architectural work, casted with pure lead, by the process operated by the Ajax Metal Company, of Philadelphia.

Adjourned. WM. H. WAHL, *Secretary.*

COMMITTEE ON SCIENCE AND THE ARTS.

[*Abstract of proceedings of the stated meeting held Wednesday, June 6, 1900.*]

MR. H. R. HEYL in the chair.

The following reports were adopted:

Machine for Tangible Writing for Touch Reading.—W. B. Wait, New York.

ABSTRACT.—The applicant submitted two machines, the object of which is to produce embossed writing by means of which the blind are enabled to write and read.

The method of Mr. Wait is a modification of the system first devised by Braille, and known by his name, in which the signs or letters consist of one or more raised points, the relative location and configuration of which determine the character.

In the Wait system, known also as the New York point system, each sign occupies the space of either one, two, three or four vertical rows of two points each. In this, as in the Braille system, the letters are separated by spaces somewhat exceeding the distance between the vertical rows in each sign, and words are divided by a still greater space.

Two machines were submitted by the inventor; one, the smaller of the two, adapted to make the impressions directly upon paper, and operated by hand; and the other, operated by foot-power, intended for producing the plates used in the process of reproducing the embossed sheets used by the blind. This machine is strong enough to make the impressions on thin sheets of brass, which are subsequently used to make similar impressions on sheets of paper. (The details of construction cannot be made intelligible without illustrations.)

The conclusion reached by the investigators is as follows: "As compared with similar machines made for producing the embossed writing of the Braille system, * * * the machines of applicant are superior, both in details of mechanical construction and in workmanship, to those previously made." The report further specially commends the ingenuity with which the "variable feeding" has been accomplished. The committee recommends the award of the John Scott Legacy Premium and Medal. [*Sub-Committee.*—Hugo Bilgram, Chairman; Edward E. Allen, B. N. Lehman, F. E. Ives, Louis E. Levy.]

System of Incandescent Lighting.—Welsbach Light Co., Philadelphia. (Referred by the Bureau of Awards, National Export Exposition.)

ABSTRACT.—This report embraces a historical sketch of the art of incandescent lighting by gas and electricity, and is reserved for publication in full. The award of the Elliott Cresson Medal is made to Dr. Carl Auer von Welsbach for his discoveries regarding the metallic oxides which may become incandescent when heated and for the invention of a mantle by the use of which these metallic oxides are commercially available as sources of artificial light.

The Edward Longstreth Medal of Merit is also awarded to the Welsbach Light Company for the successful industrial development of these discoveries [*Sub-Committee.*—Arthur J. Rowland, Chairman; Chas. A. Hexamer, Wm. McDevitt, Moses G. Wilder, Frank P. Brown.]

Improvements in Carriages and Wagons.—Chas. S. Caffrey Co., Camden, N. J. (Referred by the Bureau of Awards of the National Export Exposition.)

ABSTRACT.—This report relates to the exhibit of carriages and wagons made by the manufacturers at the National Export Exposition, and grants to them the award of the Edward Longstreth Medal of Merit for excellence in design and workmanship and for lightness and novelty exhibited in their products. [*Sub-Committee.*—Arthur M. Greene, Jr., Chairman; Chas. R. Torkington, Caspar Kendall.]

Universal Ratchet.—Waterbury Tool Company, Waterbury, Conn.

ABSTRACT.—This invention is the subject of letters-patent of the United States (No. 613,950, November 8, 1898), granted to H. D. Williams, H. G. Hoadley and E. C. Lewis. It consists of a substantial ratchet-box, with diagonal trunnions to which the operating lever is attached.

The object of the improvement is to produce the rotary movement of a shaft by means of the vibratory movement of a lever, which vibration may be in various planes, as well as in a plane at right angles to the shaft. The tool is, therefore, adapted to operate successfully in difficult situations where obstructions might make the use of an ordinary ratchet impossible, while at the same time provision is made for its operation in the usual way. For details of the mechanism, reference is made to the above-named patent specification.

The investigators find that the construction of the tool is in every respect good and substantial; that attention has been paid to the requirements for a serviceable and convenient ratchet; and that, when the facilities which it offers for meeting trying situations are considered, the space which it occupies is surprisingly small. All the working parts are case-hardened, and every detail testifies to the care taken in its design and construction as a part of a clever and ingenious whole. The inventors are awarded the Edward Longstreth Medal of Merit. [*Sub-Committee.*—Wilfred Lewis, Chairman; Henry F. Colvin, Spencer Fullerton, Luther L. Cheney, Thos. P. Conard.]

Variable-Speed Countershaft.—Milton O. Reeves, Columbus, Ind

ABSTRACT.—The invention is a device designed to give to a machine any intermediate speed between two limiting values, and to accomplish this while the apparatus is in motion.

For details of construction and operation, reference is made to United States letters patent Nos. 581,770, 583,402, 584,402, 507,403, 588,354, 603,067, 606,941, issued to said Reeves; and in part to E. K. Hood. The dates are between May 4, 1897–July 5, 1898.

The report embodies a description of the mechanical operation of the device and a comparison with other devices used for the same purpose

The conclusions are: (1) that the motion transmitted by the device is practically uniform at all positions; (2) that the belt tension can be kept practically constant; (3) that the apparatus can be changed while in motion to any speed within the limits; (4) that the power transmitted is limited by the excessive weight of the belt, which increases the centrifugal tension with-

out affording any corresponding increase in strength; (5) that the apparatus may be adapted to any machine requiring an adjustable speed, as automobiles, lathes, boring mills, etc.; (6) that the efficiency is fairly high; (7) that the apparatus wears well.

The award of the Edward Longstreth Medal of Merit is made to the inventor. [*Sub-Committee.*—Wilfred Lewis, Chairman; Arthur M. Greene, Jr., Luther L. Cheney.]

Obtaining Energy to Run Automobiles.—John Stolze, Reading, Pa.

ABSTRACT.—The applicant proposes to couple an air compressor to the running-gear of a compressed-air driven automobile vehicle in such manner as to admit of the compressor being actuated by the vehicle itself while on down grades. The air so compressed is to be added to the initial supply, stored in a suitable chamber, thus increasing the performance of the vehicle for a given initial supply of compressed air.

The investigators express the opinion that the advantage to be derived from such a combination is not great enough to give to the invention a commercial value. [*Sub-Committee.*—Geo. S. Cullen, Chas. C. Heyl.]

Double-reciprocating Square Piston Engine for Steam and Compressed Air.—W. F. Dake, Grand Rapids, Mich.

ABSTRACT.—This invention is the subject of letters-patent of the United States, issued to applicant (No. 359,039, December 25, 1888).

The engine is provided with a suitable casing having a chamber in which is held, so as to be able to move backward and forward horizontally, a rectangular piston having a chamber in which is mounted to slide vertically the inner piston, which is carried on a wrist-pin secured to a crank-disc on the main driving shaft. On top of the casing is a steam-chest with a 4-way valve controlled by a handle. Into this valve leads the steam pipe, and out of it the exhaust pipe. The engine can be run in either direction by changing the position of the said valve. The necessary ports and channel-way are provided in valve box and casings, and provision is made to prevent leakage by packing-strips, set-screws, etc.

The investigators find this form of engine very compact, permitting it to be used where engines of the usual types would be excluded on account of space. The Dake engine, however, requires fine adjustment when made and will soon begin leaking if not well balanced. It shakes badly at high speed, and uses more steam than many others doing the same work. This type of machine is suitable only where the work is intermittent, and even in these cases is not altogether satisfactory. [*Sub-Committee.*—L. F. Rondinella, Chairman; J. M. Emanuel, Henry F. Colvin.]

The following reports passed first reading:

Artificial Production of Graphite.—E. G. Acheson, Niagara Falls, N. Y.

Hydraulic Air Compressor.—Continental Compressed Air and Power Company, Philadelphia. (Referred by the Bureau of Awards of the National Export Exposition.)

Incandescent Lamp.—International Incandescent Light Company, Philadelphia. (Referred by the Bureau of Awards of the National Export Exposition.)

These reports were held over under advisement until the next meeting.

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Stated Meeting, February 21, 1900.

THE DEVELOPMENT OF THE AMERICAN COTTON INDUSTRY.

BY FRANK HART.

It affords me great pleasure to address you to-night on the influence of machinery upon the culture, handling and manufacture of cotton in the United States.

India seems to have been the birthplace of cotton culture and manufacture, as of so much else for which we are indebted to that ancient civilization. For 3,000 years, or until the seventeenth century, it was the cotton-weaving center of the world.

While the industry was nowhere else so highly developed at so early a period, cotton was in prehistoric times grown and spun in many parts of the world. The Egyptians were, probably, familiar with it. At the time of Columbus' dis-

covery the fiber was grown and made into cloth by the inhabitants of the West Indies, Mexico, Peru and Brazil. Cotton cloth has been found in the ancient tombs of the Peruvians. Mexico, under the Montezumas, knew neither wool nor silk, and, although it possessed the plant, did not use flax. It is estimated that prior to the Conquest 116,000,000 pounds of cotton were grown annually by the Aztecs, more than four times as much as is produced by their successors in Mexico to-day. Singularly enough, the only region in the Western Hemisphere between the parallels 40° north and 40° south that did not grow cotton prior to the discovery of America is that occupied by the Cotton States, which now produce three-quarters of the world's entire yield.

Herein is seen the influence of machinery, that worker of miracles, which has transformed the face of the earth, annihilated space and time, and made the forces of nature to do the work of man.

It may be true that without machinery cotton would ultimately have been an important article of our Southern agriculture, but it cannot be doubted that, except for this factor, the history of the staple in this country would have been far other than it is, and that instead of enjoying a virtual monopoly of the cultivation of cotton, the South would have borne but an insignificant part in its production.

The first of the colonies to plant cotton was Virginia, in 1621. It was not until 1747 that any cotton was exported, and then only a few bags valued at less than $20. In 1770 three bales were shipped to Liverpool from New York; ten bales from Charleston; four from Virginia and Maryland, and three barrels from North Carolina. In 1786 900 pounds of cotton were exported to Liverpool. The next year the exports to England aggregated 16,350 pounds. In 1790 only 2,000,000 pounds of cotton were grown in the South. The following year 189,500 pounds of American cotton were shipped to Liverpool, the price paid on this side averaging 26 cents per pound.

The foregoing figures represent the growth of cotton culture in the Colonies in 170 years. He would have been set down as a visionary who should have foretold what the next

century, under the impulse of a mighty force harnessed by the genius of man, was to bring forth.

The inventions of that galaxy of mechanicians—Hargreaves, Arkwright, Crompton, Cartwright and Watt—ushered in one of the mightiest of modern industries, and created a demand for more cotton than the world produced. If the South could not be freed from dependence on the devices then in use, it was not to be expected that the increase would be supplied by the United States. To have grown the cotton would have been easy; the difficulty lay in its preparation for market. The lint had to be separated from the seed by hand, a slow and expensive process, which even at the high prices that then prevailed left little return for the cotton farmer, and restricted the growth of the staple in the South practically to the requirements for domestic use.

Whitney's invention of the cotton gin in 1793 made possible the production of cotton in America as a commercial crop. The effect on the South was magical. In 1796, a year after Whitney had improved his machine, the yield had risen to 10,000,000 pounds. In 1800–01 the South produced 48,000,000 pounds of cotton, or 96,000 bales of 500 pounds net. Production grew by leaps and bounds. In 1806–07 it was 160,000 bales; in 1816–17, 260,000 bales; in 1840–41, 1,288,000 bales. By 1859–60 the crop had grown to 4,482,000 bales of 500 pounds net.

Cotton was indeed king! Its production had become the most important agricultural pursuit in America; its producers the wealthiest farmers the world had ever seen. The Civil War paralyzed the industry, but after the return of peace the yield grew steadily, until in 1897–98 it reached 11,216,000, and the year following 11,256,000 gross bales.

As the purpose of this paper is not to set forth in detail the history of the culture, handling and manufacture of cotton in this country, but merely to point out what has been accomplished by the aid of machinery and to indicate what yet remains to be done, in discussing the third phase of the subject, which, for convenience, will be treated before the second, I shall do no more than refer to the growth of cotton spindles in America. The pioneer of an industry which

has contributed enormously to the wealth of New England and the Middle States, and is just now quickening the South to stupendous activity, was a cotton mill erected at Beverly, Mass., in 1788. It was soon followed by others in New England, New York, New Jersey, Pennsylvania, and at Statesburg, in South Carolina.

Although possessing the strategic advantages of cheap labor, abundant water power and proximity to the cotton fields, the South neglected until after the Civil War to avail herself of them. For three-quarters of a century she was content to supply the raw material whose fabrication enriched the North, England and Continental Europe. The past two decades, however, have witnessed an industrial revolution in the South. This favored region has become an important, and promises at no distant period to be the dominant, factor in the cotton manufacturing situation. Last year, it is estimated, mills were built or begun in the South, requiring in the aggregate 1,824,000 spindles and 23,300 looms, and involving an investment of $33,714,000. Mr. D. A. Tompkins, the cotton mill expert of Charlotte, N. C., estimates that 2,000,000 spindles will be installed in Southern mills this year.

To quote this authority: "There are now 5,000,000 spindles in the South, 13,000,000 in New England and 2,000,000 in other States. England has 46,000,000 spindles. If the present rate of increase, 2,000,000 a year, continues, in ten years the United States will have 45,000,000 spindles, of which the South will have 25,000,000—more than New England and the Middle States combined."

Not the least of the South's debt to machinery is owed to the invention of processes for the utilization of the cotton plant's by-products. Although the value of cotton-seed oil was known in the last century, it was not until about 1850 that it was produced as an article of commerce. In 1867 there were only four oil mills in the South. Now there are several hundred. In an average season they crush 1,500,000 or 2,000,000 tons of seed, which yield cotton-seed oil and other products having a value of some $30,000,000. Probably not more than 40 per cent. of the available cotton seed reaches

the oil mills. When all of the crop, except the requirements for reseeding, finds its way there to be converted into oil, cattle feed and fertilizer, the South will receive a revenue of some $60,000,000 or $70,000,000 annually from a by-product, of which, in ante-bellum days, almost no use was made.

Unfortunately, the handling of cotton has not kept pace with its production. Save the roller gins employed for delinting Sea Island cotton, the gins used now, while vastly improved mechanically and of greatly increased outturn, are in principle the same as that invented by Whitney. They are made up of gangs of seventy or eighty circular saws, working between ribs, the teeth of which tear the lint from the seed and greatly injure the fiber. In old-style gin-houses the lint, as it leaves the condenser, is thrown into the gin press, by which some 500 pounds of cotton are pressed into a rectangular bale weighing about 12 pounds per cubic foot. This bale is partly covered with coarse jute and rudely bound with six or more iron bands, which, with the bagging, weigh some 22 pounds.

From the moment it leaves the gin-house the square bale's troubles begin. It is taken first to the local cotton market, where it is freely sampled by country buyers. Thence it is delivered to the railroad to be conveyed to the nearest compress. Inasmuch as a quarter of the Southern cotton crop annually moves to the local freight stations in thirty days and three-quarters in four months, the railroads are utterly unable to handle the traffic. Blockades result. The cotton lies uncovered on the local depot platforms or on the bare ground, often as long as six or eight weeks, exposed to the elements. Arrived at the compress it awaits its turn to be compressed. The result of this treatment is "country damage," claims for which at the single port of Liverpool aggregate $500,000 a year.

In the compress the gin-bale is subjected to a pressure of from 2,400 to 3,000 tons and reduced to about half its former thickness, or to a density of some 22 pounds per cubic foot. The ties are shortened and the side pieces, if any were put on at the gin, are taken off. The compressing, which costs 50 cents a bale, occupies but a few seconds,

and resembles a blow from a ponderous steam hammer. Along with the cotton much air is compressed in the bale, which by supporting combustion in the interior, where the fire cannot be reached, makes of the square bale of cotton a veritable fire-trap. The jute bagging, with which a pretense is made of covering the bale, affords almost no protection to the lint. Loosely woven, it readily permits the absorption of moisture. More inflammable even than the cotton itself, it invites rather than prevents fire.

It was inevitable that this crude system would be superseded by a better. Indeed, the wonder is that the square bale abuses should have been tolerated so long. It was early recognized that the root of the evil was the bale itself, and that any improvement, to be of value, must begin with a better bale. It was seen, too, that the cotton bale of the future would be cylindrical in shape. The first attempts at forming a round bale were made more than 50 years ago. A machine for rolling up cotton in the shape of a cylinder was patented by North in 1848, but nothing came of it. Many subsequent attempts were made with equal want of success. The chief obstacle lay in devising a machine that would put up cotton under pressure in a bale perfectly round; otherwise it was impossible to secure sufficient density. The greater the pressure applied to a bale of uneven formation, the more out of round it became, and it soon stopped revolving altogether or resulted in a comparatively soft bale. The next difficulty was in so regulating the pressure as to prevent hard centers.

For many years mechanical minds labored to solve these problems. The American Cotton Company's roundlap press is the sum of their combined efforts. It is covered by more than fifty patents and represents the expenditure of vast sums of money. The press has two horizontal rolls, and a hydraulic cylinder connected with a large air chamber regulates the pressure automatically.

To insure uninterrupted operation the press is now built in duplicate. Attached directly to the gins, it takes up and bales, without stopping for the removal of finished bales, the entire output of from three to eight 70- or 80-saw gins.

On its way from the gins to the press the lint passes through a lint flue equipped with dirt pockets by means of which all sand and dirt are removed. From the lint flue it passes over a condenser having a velocity of about 50 revolutions per minute. The cotton, barely touching the condenser drum, is thrown off, the air and dust pass through the wire cloth above, while the cotton, a fluffy mass some 5 feet thick, passes on over and falls into the bat-former—comprised of two converging aprons, whose adjacent surfaces travel in the same direction—which delivers it to the compression rolls in a uniform bat 10 or 12 inches thick and weighing $2\frac{3}{4}$ pounds to the yard. This bat moves at the same speed as the press. Thus a continuous lap of cotton is made that unrolls as easily as it is rolled up. As it passes beneath the compression roller the air is excluded and the compressed cotton is wound around a core under a pressure, which, light at first, is gradually increased automatically until the bale attains its full size. In this way, by the steady exertion of an even pressure of less than 15 tons gradually applied to all the cotton in detail, a bale is produced having a density of 35 pounds per cubic foot, as against the density of 22 pounds attained by the square bale after a second compression in which a force 200 times greater is employed in one ponderous blow directed against all the cotton in mass.

By reason of this moderate pressure, gradually applied as the bat moves forward under the roll, one end of every strand of cotton is in effect fixed while the pressure of the expelled air straightens out the fiber and it is caught and held in that position. This action and the pressure are not so great as in any way to affect the natural spirality of the cotton fiber so important to the spinner or to injure the fiber in the smallest degree. The air having been pressed out, the bale, besides being rendered practically indestructible by fire, is self-containing, has no tendency to expand and does not require iron ties. When the bale is of proper size it is completely covered with a light, closely woven, inexpensive burlap, which keeps the cotton clean and dry. Weighed, marked and tagged, the bale is ready without

further compression for through shipment to the mills in America or to ports abroad. Formerly bales were made 48 inches in length and 25 inches in diameter. Thirty-five inches having been found a length more suitable for handling at the mills, the presses are built to turn out bales of that length, 22 inches in diameter and weighing 270 pounds each.

While the bale is being made, an uncompressed sample 10 x 24 inches and about 4 inches thick is drawn and divided into two pieces, each about 10 x 12 x 4 inches. These are tagged to correspond to the tag number of the bale, one is sent to the American Cotton Company and the other is retained by the ginner or delivered to the owner of the cotton. On samples taken in this way the American Cotton Company has bought hundreds of thousands of roundlap bales, which it has in turn without further sampling sold, with fewer disagreements and reclamations than would have accompanied a square bale business of equal magnitude. While sampling is entirely unnecessary, if for any reason it is desirable, a roundlap bale can be resampled as readily as a square bale.

In furtherance of its purpose to insure to the South that the economies of its baling process shall be reaped in full, the American Cotton Company has organized a system for the through handling of cotton from gin-house to mill. In order to insure a ready market for all cotton baled on its presses, the Company became a cotton buyer to the extent of agreeing to buy any and all cotton properly put up in roundlap bales, and to pay therefor 45 cents per hundred pounds more than the market price of the same cotton in old-style bales. This premium is the first fruit of the roundlap bale economies, and it is paid to the planter.

It is impossible within the limits of this paper to do more than allude to the savings effected by the roundlap bale. The elimination of the necessity of a second compression, although the keystone of the roundlap system, is only one of many economies. As against bagging and ties for a 500-pound square bale, which, as has been said, weigh 22 pounds, and cost 75 cents, the covering for an equivalent of

cotton in roundlap bales weighs 5 pounds and costs 25 cents. Besides this initial saving of 50 cents per bale in the cost of covering, there is a further saving of freight on the 17 pounds excess weight of bagging and ties. Colonel A. B. Shepperson, the eminent cotton statistician, in considering this phase of the cotton handling question, in the latest edition of his "Cotton Facts," points out that, owing to this excess weight of bagging and ties, in the marketing of the 1897–98 and the 1898–99 cotton crops freight was paid on the equivalent of over 800,000 old-style bales more than would have been required to market those crops in roundlap bales. Estimating that the cost of transporting cotton to the mills averages $6.25 a bale, which is believed to be well within the actual figures, the freight charge against these two crops, arising from the excess weight of bagging and ties, was $5,000,000 more than it would have been had the Southern staple been marketed in roundlap bales. This does not take into consideration the freight originally paid in sending the surplus weight of bagging and ties to the cotton plantations, which was not less than $2,000,000 for the two crop years in question. Thus in two seasons the South paid $7,000,000 in needless freights on the surplus weight of the materials used to cover its cotton—materials, moreover, which not only do not protect the staple from damage, but fail to preserve intact the package they are employed to make.

This loss is small beside that involved in the transportation of the old-style bales themselves. Uncompressed square bales, loading to one-fourth, and compressed square bales, to one-half the weight capacity of cars, pay rates based on full carrying capacity. Roundlap bales, on the other hand, load to the full weight capacity of freight cars. Shipments of the American Cotton Company's bales weighing 68,628 pounds and 72,226 pounds, respectively, have been made in a single car. Roundlap bales being shipped from gin-plants through to the mills in this country or to cotton ports abroad, the employment of rolling stock in the profitless traffic of concentrating cotton for compression is obviated. Competent railroad authorities estimate that

roundlap cotton can be handled with one-fifth the number of cars required to market the equivalent of square cotton. On shipboard roundlap bales stow with a saving of one-third the space occupied by square bales, with greater ease of handling and without needing to be screwed in. If the average freight charge for carrying Southern cotton to the spindles of the world is $6.25 per 500-pound bale, the marketing of a 10,000,000-bale crop involves an expenditure of $62,500,000 for freight. That roundlap bales can be carried by railways and steamships at a saving of one-third the cost of transporting square bales is an estimate that leans to the side of conservatism. If this be true, it follows that when the adoption of the roundlap baling system becomes general throughout the South $20,000,000 will be saved annually in the expense of transportation.

It is estimated that raw cotton pays every year some $4,000,000 for marine and fire insurance, Of this, $500,000 goes to pay the "country damage" claims on square cotton received at the single port of Liverpool. At least half as much more is required to pay "country damage" claims arising elsewhere. Here is three-quarters of a million dollars that can be saved annually by the roundlap bale, against which there has never been a claim for "country damage," to say nothing of the large saving in marine and fire insurance premiums due to the roundlap bale's superiority as an insurance risk.

The petty leaks, small as they seem in themselves, grow in the marketing of a season's crop into stupendous losses. From the gin to the mill square bales change ownership from three to five times, and are as often reweighed, re-examined and reinsured. Every time a bale is sold, and frequently when it isn't, it is sampled. Between sampling and theft, the square bale loses first and last some 5 pounds of lint, which, baled, go to make up the "city crop." This crop is wholly independent of climatic conditions and never fails. It is estimated by a well-known statistician to yield annually 100,000 500-pound bales, worth to the farmer, at 7 cents a pound, $3,500,000. Hon. I. F. Culver, Commissioner of Agriculture of Alabama, in a paper read before the

Cotton States Association of Commissioners of Agriculture, in Atlanta, Ga., in October last, estimated the expense of reweighing, re-examining and reclassing square cotton, exclusive of the lint lost, at 30 cents a bale, or $3,000,000 annually. Mending square bales costs not less than 10 cents a bale, or $1,000,000 for an average crop.

Square bales are sold abroad less 6 per cent. tare. The covering for the American Cotton Company's bales weighs 5 pounds for each 495 pounds of lint. When cotton thus packed reaches the ports abroad, clean and uninjured, it weighs exactly what it weighed at the gin, the covering weighs no more and no less than when it was put on, and the bales are sold less 1 per cent. tare, a saving of 5 per cent.

The saving at the mills begins with the unloading of the cars. The most approved method of handling roundlap bales is to place three or four bales directly on the apron of the breaker lapper, from which they unroll automatically directly into the machine. There are, besides the material saving of expense, further savings of wastage and loss of weight. A comparative test of roundlap and square cotton was made in the Massachusetts Cotton Mills, of Lowell, Mass., last month, to determine the relative shrinkage in weight by drying out. The cotton was opened, loosened by hand, placed in new bags and allowed to stand 184 hours before being reweighed. The square cotton showed a loss of 2·283 per cent., the roundlap cotton a loss of 1·271 per cent. The saving in favor of roundlap cotton was 1·012 per cent., or 4·837 pounds per bale of 478 pounds net. It is impossible to express in terms of money these economies at the mill, but a mill owner, whom an experience of several years in the use of roundlap cotton has enabled to give the subject careful consideration, estimates them at not less than one-eighth of a cent per pound.

According to the foregoing estimates, all of which are believed to be conservative, the savings which would accrue from the marketing of a 10,000,000-bale crop in roundlap bales may be summarized as follows:

On bagging and ties	$5,000,000
Compressing 80 per cent. of square bales	4,000,000
Freight	20,000,000
Screwing in and labor saved at ship's side	1,250,000
Unnecessary sampling and theft	3,500,000
Insurance (including country damage)	1,500,000
Reweighings and yardage	3,000,000
Mending	1,000,000
At the mill	5,500,000
Total	$44,750,000

This enormous sum is the annual tax imposed on the cotton States by an unscientific system. It means that $4.50 of the proceeds of every square bale of cotton is wasted. The roundlap bale saves all this waste. Its economies accrue not alone to the profit of the producers of cotton, the common carriers, the makers and operators of roundlap baling presses and the users of roundlap bales, but they may be shared also by responsible cotton buyers, merchants and bankers and by every other legitimate commercial interest engaged in the marketing of this great staple.

Mechanical and Engineering Section.

Stated Meeting, held February 8, 1900.

FIRE HAZARDS.

By H. de B. Parsons, M.E.

"An ounce of prevention is worth a pound of cure" is an old adage containing much that is worth practicing. The ratio in the phrase is one in sixteen, but are there many who put, out of sixteen chances, one on the side of safety? With fire risks, it would seem truer to place the ratio at one in a hundred and alter the phrase to suit—a cent of prevention is worth a dollar of cure. Even that proportion of the cost of a building is rarely spent to reduce the fire hazard. Nearly every one figures on a loss by fire as one of money

alone, which may be covered by insurance. Unfortunately, fires cause losses that are not so protectible, such as loss of life, of treasures, of archives and of time, none of which can be replaced.

Many owners of buildings spend large sums in fire apparatus, extinguishers and the like. The same amount of money and energy spent on original construction and design would have been more effective. The author is fully aware of the value of these agents, and does not desire to belittle them. While the original weakness still exists they can only act by lessening the extent of the hazard, or, in other words, their successful application depends on something other than the building itself.

The value of a building depends upon its income-earning capacity, and it is a well-established fact that safe buildings command little, if any, additional rent over those in which such qualities are but veneer. Tenants are guided chiefly by modern conveniences and showy appearances.

The total amount of risks in force in the United States by United States fire insurance companies and by branches of foreign companies on December 31, 1898, amounted to $36,984,810,997. The average premium was about 90 cents on each $100 of risk. The fire losses paid during that year were $71,785,247.

If more forethought were given to the details of design and construction, a large sum would be saved annually in insurance premiums. To illustrate, the owners of a certain building told their architects to produce a structure that would be classified at the lowest rate of insurance for the business intended. Owing to neglect of proper column protection, this building was annually charged an excess of premium of $3,000, or the interest at 6 per cent. on $50,000. The columns could have been protected for less than this figure, and as the building could have been mortgaged for 4 per cent. or less, the saving would have exceeded $1,000 per annum.

Many imagine because iron and steel are incombustible (in the ordinary sense of the word), that buildings constructed of such materials, together with glass, bricks, and cement, can always be classified as fire-proof. Such build-

ings may be proof against an internal fire when empty, but, unfortunately, full consideration is not always given to the effect of inflammable contents, or of the hazard caused by a neighboring structure.

The design of a really fire-proof building is more difficult of execution than generally imagined. The term "fire-proof" has become generic, and is, in many instances, a misnomer. In its broad sense, it is used to classify a certain style of modern construction that has become very popular, as is attested by the wonderful and rapid growth of such buildings in our cities.

It is impossible to conceive of a building that could not be damaged by fire. The more fire-proof a building is made, the greater will be its cost and the less its utility for modern demands. The problem is economic, and must be settled by balancing the questions involved.

A fire-proof structure may, then, be defined as one that will be damaged by fire to a minimum extent, while considering the hazards from within as well as from without; one in which the injury will be localized, and one in which the main-supporting or weight-carrying members will not be injured to an extent that will render them useless.

The ordinary method of construction, with brick and stone walls, wooden beams and floors, is in no sense fire-proof, and the hazard is great, depending on its use, exposure and class of tenant.

The destruction of the Burdette Block, in Troy, N. Y., on February 17, 1896, cost four lives, and was caused by the careless dropping of a match. The fire took place while the thermometer was at zero or just below, and the ice formed in the streets as high as the tops of the basement store windows and completely covered the whole front, making a most beautiful spectacle under the bright sun of the day following. The building was of the ordinary wooden beam and floor construction, and was consumed with fearful rapidity.

While buildings of this construction cannot be designed as fire-proof, still much can be done to render them slow-

burning by proper division with fire-proof walls made self-sustaining.

The Washburn & Moen Manufacturing Company's Quinisigamon Works, Worcester, Mass., were destroyed by fire on April 5, 1899. This building was built on the "cage" type of construction, consisting of a steel frame supporting the floors and roof, with enclosing walls of brick built in between the posts. The posts and beams were of steel, spaced 8 feet on centers. The window frames were of steel, and the only wood employed was in the floors and roof. The building was used for the manufacture of steel springs, and the floors were not heavily loaded. The fire spread with extreme rapidity, partially due to the vapors of oil which had condensed on the ceilings.

The general lesson of this fire was the inability of steel and iron to withstand heat, and the futility of attempting to build an iron or steel fire-proof structure unless the metal be thoroughly protected. Had concrete floors been used in place of wood, of course much of the combustible material would have been removed from this particular building, but the risk would have been great had the contents been combustible, or had it been exposed to an adjacent hot fire.

Witnesses of this fire stated that the columns and beams began to yield by bending within from fifteen to twenty-five minutes after the fire started. Nothing could have been more complete in the line of destruction.

The temperature of this fire can only be inferred from the effects. A cast-iron cone pulley was found which showed evidence of having been heated to a plastic condition, and a portion of a cast-iron cylinder of having been melted. Cast iron melts at about 2,000° Fahr.

Various tests have been made on unprotected metal columns which have shown failures similar to those in actual buildings.

The following table gives the data of fire tests on unprotected columns made by the Committee on Fire-Proofing Tests in 1896:

Test.	Weight of Column.	Conditions.	Temperature.	Load, Tons.	Time.
1	823 lbs. steel	Slow heat	1,200°	46·0	1 hr. 21 m.
2	690 " "	Rapid "	1,175°	84·8	0 " 23 "
3	928 " C. I.	Slow "	1,100°	84·8	1 " 8 "
4	928 " "	Rapid "	1,350°	84·8	0 " 35 "
5	928 " "	Slow "	1,200°	84·8	2 " 15 "

Each column was designed to carry about 85 tons as a full safe working load. In each case, the time mentioned is given from the moment the fire started until the column began to yield by bending.

Test No. 4 was suddenly terminated by the fracture of the column without warning.

Test No. 5 was prolonged by repeatedly cooling the column with water.

None of the columns began to yield until they showed "red," so that it may be inferred that they would have continued to carry their loads had they been protected, or had the loads been less than their safe capacity.

For buildings intended for manufacturing and for certain kinds of mercantile business, a form of design known as the "Slow Burning" or "Mill" construction is to be preferred to any form of iron or steel construction with unprotected members. This construction makes use of timber for posts and girders, over which is laid a flooring sufficiently thick as not to require joists. The best forms use double floorings with tin, salamander or some other fire retardent between them. The posts and girders should be of such scantling as to permit encroachment by fire to a depth of about 2 inches without impairment of strength for their respective loads, as it has been found to require a long period before fire will char a heavy timber to a greater extent. Great care should be exercised to see that there are no air spaces left in the construction.

Modern mills are made too wide to permit the beams to span from wall to wall, as was the practice in older forms. Posts, therefore, must be adopted. No matter what material is used, the design should contemplate fire resisting and fire retarding. This latter can be accomplished by use of fire

walls, self-sustaining, so placed as to separate or cut the building into sections. Access can be provided by openings closed with fire doors, the best form of which is probably that known as the "Underwriters" type. These walls should extend through the roof about 3½ feet, and project out through the sides of the building about 2 feet when there is danger of the fire spreading through windows.

The chief hazard, other things being equal, is the danger caused by draft up the hatchways and stairs. This hazard can be remedied by making such openings in a separate, tower-like building into which connection can be made by bridges at the different floor levels. When the ground plan will not permit of this arrangement, the hatchways and stairs can be placed in a narrow section, separated off by fire walls on each side, with the openings into the main parts of the buildings located so as not to be opposite, and equipped with double fire doors.

In no form of construction should heavy weights, such as tanks, be supported on or suspended from the tops of buildings, unless such weights be carried on some permanent form of fire-proof construction fully protected.

As an example of this defect may be mentioned the Windsor Hotel, in New York, which was destroyed by fire on the 17th of March, 1899. This fire took place during the daytime, when every advantage was afforded the fire department, with the exception of a prompt alarm.

This building was of the ordinary brick construction, in plan like a flat U, 200 feet long, 180 feet deep and eight stories high, having a light court in the rear; and classified by firemen as a "quick burner" owing to the wide corridors on each floor and lack of fire division walls. There was a large water tank on the roof at the center of the front, said to contain about 100,000 gallons; and it has also been stated that, owing to some change in original plans or in lack of foundation support, part of the building was suspended from girders across the top of the building.

The fire is supposed to have started about fifteen minutes before the alarm was given. It originated in the basement and extended throughout the structure with fearful rapidity.

The fire enveloped the center of the building, passing up the elevator shafts and court, and spread to each floor of the Forty-sixth Street or south wing, working its way towards Forty-seventh Street through the corridors on each floor. The front wall under the tank began to fall about thirty-five minutes after the fire started; ten minutes later the Forty-sixth Street walls fell outward; and twenty minutes afterward the Forty-seventh Street wall gave way.

Many buildings of merit are more vulnerable from fire without than from fire within. The "exposure" is frequently of far greater import than risks of other character, and designers fail, as a rule, to give due weight to the value of these external hazards. The design may be such as to render it difficult for a fire to obtain much headway within the building before it is discovered and placed under control, while the same building would be most susceptible to damage if a fire should occur in the immediate vicinity.

Serious damage was done to the Manhattan Savings Institution Building, New York, through a conflagration on the opposite side of the street, during the winter of 1895–1896. This building was modern, but contained a large window area. The metal girders were unprotected, became heated, expanded, thus pushing out the walls, and finally buckled and dropped the floors.

As another example of exposure, the Methodist Book and the Horne Buildings, in Pittsburg, Pa., may be cited. These buildings were of modern and so-called fire-proof construction, yet they were completely wrecked by fire from without, on the 3d of May, 1897.

A fire started in an old building of brick and wood, partly constructed on the "slow-burning" principle, filled with combustible material, and spread to three modern steel fire-proof buildings and some five or six small buildings of ordinary construction used for shops and dwellings. These latter were completely wrecked, while the former offered resistance, although the contents were ruined. The fire was very rapid and the heat intense. The front of the Horne dry-goods store was nearly all window area and the plate glass could not resist the heat from across a street 65

feet wide. The divisional partitions were few, imperfect and badly located as fire stops, and the floors communicated through numerous openings and light wells. The adjacent Durbin Horne office building resisted better because of its divisional partitions. The metallic frames were damaged less than might have been expected, and the various systems of fire-proofing stood fairly well. The cause of the great damage was not due to the fire-proofing, but to the total disregard of the hazard of exposure.

The Horne dry-goods store contained a 5,000-gallon tank, which fell from the roof, carrying away in its flight the beams and columns. This tank was supported on a system of unprotected beams. The light court acted like a flue, and the fire on each floor was drawn to it under the draft from the broken windows.

The self-sustaining brick walls and the metal framework of the Durbin Horne office building were little injured, largely, if not entirely, due to the existence of the partitions. The floor arches resisted well, but the skew backs failed in many places. The contents were completely gutted, as the fire was fanned by a strong draft through the floor openings.

The Methodist Book Building was not subjected to the same degree of heat as the Horne buildings, and the fire simply wrecked the upper stories. This building had a concrete system of flooring.

The Home Life Building, New York, a modern "skyscraper," became the object of a severe attack by fire on December 4, 1898.

It had sixteen stories, was 192 feet in height to the roof and 242 feet to the top of the tower. There was a light well in the middle of the north side, and along this light well were the elevators and the staircase. The side and rear walls were of brick, while the front was of marble ashlar backed with brick, built solid from the foundations. The building, with the exception of the front wall, was constructed on a skeleton framework of steel. The walls, columns and girders were covered with porous terra-cotta furring, the floors of hard-burned terra-cotta blocks and the

partitions were partly of porous terra-cotta and partly of wire lath and plaster. These partitions were cut with large openings for light, finished with plain glass transoms set in wooden frames. All the windows were of plate-glass, set in wooden sashes and no shutters were used. The room walls and ceilings were plastered. The floors, except the halls, which were of mosaic blocks, were of wood nailed to sleepers, without any concrete filling. There was also a varnished base, chair-rail, window-, door- and transom-trim of wood.

On the north, there was a corner building, five stories high, of ordinary brick and wood construction, occupied as a retail clothing store. A northeasterly gale drove the flames from the clothing store against the wall of the Home Life Building and into the light well, which acted as a chimney. The fire entered the unprotected windows of the eight upper stories, and found inside a natural draft through the elevator openings. The result was the total destruction of the contents and all combustible materials of construction on those floors, practically nothing being left but the absolute fire-proof material. The plaster work was destroyed, and in all the rooms from the ninth floor up there was hardly any plaster left on the terra-cotta furring. The wire lathing used over the pipe chases in the walls and over the various irregularities in the building did not withstand the attack of the flames. This was probably due to the fact that the metal expanded sufficiently to throw off the plastering, which had little flexibility. The woodwork was completely burned. Those partitions which were cut for the purpose of inserting large transom windows near the ceiling suffered most. The glass in these transoms broke and permitted the flames to spread from room to room, thus removing the value of these partitions as fire stops.

Some of the wire-lath partitions were built directly on the wood flooring, and their failure was caused by the burning of the wood, thus depriving them of their natural support. The wood flooring was laid with an unfilled air space between it and the floor arches. This space should not have existed, and had it been filled the floors would have stood

much longer. The effect of using other material than wood for flooring is strikingly illustrated in the halls, where the mosaic blocks retained their position and were practically uninjured, although subjected to the fiercest part of the fire.

A distorted girder on the sixteenth floor probably represents the greatest damage done to any one member of the metallic frame. It was protected on the soffit by terra-cotta blocks and wire lath. It differed, however, from the other girders in having its upper chord project above the floor. The part projecting was not protected by fire-proofing material, but was boxed in with wood, forming an elevation in the floor space of these rooms. The metal became exposed to the fire and buckled.

As a fire stop, the Home Life Building succeeded admirably, for had it not been there it is fearful to contemplate what might have resulted during a gale of almost hurricane force. Taken as a whole, the building resisted the action of fire remarkably well considering the severity of the test. The fire department was powerless to reach beyond the eighth floor, and the water tank of the building was soon rendered useless. The steel structure, with the exception of a few portions, was retained without repairs. The damage to the floor arches was slight. The front wall, however, was ruined on the marble façade from the eighth story up. No doubt the destruction would have been much less had the same care and energy been bestowed upon the details of construction and finish as were given to the main framework, general plans and architectural appearance.

Only few modern tall buildings have been seriously injured by fire, but abundant knowledge has been gained from general fires to allow the making of certain statements. Judgment should not be drawn from isolated cases. Experience in fire hazards to be of value must be based on a study of many fires, as results depend as much on variable conditions, wind, draft, exposure, contents, efficiency of fire department and the like. In the same way, it is not safe to draw conclusions from experiments, unless they have been made with the greatest care to ex-

clude extraneous conditions. The unexpected is always happening, and preparations should be made for all contingencies.

BRIEF SUMMARY OF THE PRINCIPAL HAZARDS.

A tall building, having openings in the floors from the roof to the basement, resembles closely a chimney stack.

The contents and trim are the fuel in a fire-proof building, and the air enters the windows, doors and other openings to support the combustion. As the contents are beyond control, it is essential that the design should be as dissimilar as possible to that of the furnace and chimney. The air supply should be under some restriction, by keeping the windows and door openings tight, and resistance should be offered to all tendency to flue draft, by partitions and division of floors. Openings in a vertical line should not be encouraged, but when necessary for elevators and stairs such openings should be cut off from the rest of the building by fire-division walls.

It has repeatedly been proven that unprotected metal construction cannot withstand fire, nor can it be called "slow-burning." No matter how "fire-proof" a building may be, it will be ruined if there is sufficient combustible material to create a hot fire lasting for sufficient time. The metal must be kept below the point of "redness." Metallic members should be made of at least sufficient thickness to prevent rapid heating, even though they have excess of strength to withstand the stress to be actually carried.

For a building of good modern construction, the fire hazard of exposure is greater than the risk of fire within, and precautions should be taken in the original plans. This is seldom done, as the exposed sides are primarily designed for some architectural effect. A building is liable to take fire from an external hazard on every floor at the same time, a condition most difficult to control, and one that would never exist naturally from internal causes.

Modern tall buildings make most efficient "fire-stops," but they are not designed for that purpose.

Manufacturers have produced many forms of fire-proof-

ing protection, and have striven to obtain something that will not burn. Architects and engineers have given too much attention to the substance of which the fire-proofing is made, and not enough to its proper application.

No building material has better fire-resisting qualities than good hard-burned brick set in cement mortar. Most stones are injured by heat, and marble, granite, sandstone and slate are liable to disintegrate or fracture under the action of heat and water. All fancy ornamentations of stone, such as balconies, cornices, trim, etc., are extremely dangerous, from the fact that they are liable to fall during the conflagration.

Terra-cotta in certain forms has been used for trim, but it has been found that terra-cotta, while a good fire retardent, will be seriously damaged on the thin edges, and will necessitate subsequent removal and renewal. The cost of this renewal of stone and terra-cotta on the façade of a building will be much greater than the cost of the actual material injured, as much of the backing will have to be taken down although in itself uninjured. This was shown in the Pittsburg and Home Life fires.

Bonds and pier caps are frequently made of stone and subjected to great weight. As these are usually unprotected, they are dangerous, and it would be much better to use cast iron. In the same manner, stone columns carrying great weight cannot be recommended; their unreliability to withstand the action of the heat and water is an item which must be kept in mind, both from the financial viewpoint of cost of renewal and from the danger of failure, thus dropping part of the building which otherwise would have stood.

The floors should be solid to prevent the fire from spreading, and the beams and girders be well imbedded and protected so that no part of the metal will be exposed. While most fire-proofing substances have proved to be excellent, it must be remembered that there is a choice of grades, and that many of those grades are deficient in fire-resisting qualities. The greatest weakness with all floor-arch blocks is an exposed thin edge. Most arches have such an edge, covering the lower flange of the floor beams. These thin

edges are apt to break off and expose the metal. It is still an unsettled question whether hard-burned tile, porous-hollow tile, ordinary bricks or solid construction of cement is the best.

The under side of floors, forming the ceiling beneath, should always be finished flat and smooth. The custom of having a panelled ceiling, by permitting girders and beams to project below the main level, should not be sanctioned without penalty, as it is difficult to protect these important members when thus arranged and to prevent them from retaining the smoke and heat in the pockets thus formed. The consequent local heating and irregular expansion may cause serious trouble. When such projections must exist, it would be well to supply a false ceiling made with expanded metal and plaster.

In tall buildings, where the ground area is limited and valuable, it is not feasible to construct the floor without openings. Fire can only spread from floor to floor through such openings, for light, stairs, elevators, dumb-waiters, chases for pipes and wires, etc., or externally from window to window. This hazard is grave, since it can only be overcome at the cost of inconvenience and considerable expense. The modern mill construction is admirable in this regard, where the floors are solid and the openings are made in an adjoining tower-like building, or in parts separated and cut off by permanent fire walls. As both of these methods are wasteful of area, they will not be countenanced by owners of tall buildings for city use. The closest approximation to such mill practice, however, should be adopted. The elevator and stair wells should be enclosed in fire walls of brick, with all combustible material removed. Elevator entrances are usually open lattice work, a hazard which could be rectified by using fire doors or metal roller shutters that could be closed in cases of emergency. Openings for pipes and wires should be packed with non-combustible material. Any opening will act as a flue, and it is remarkable how rapidly fire will pass through the smallest crevice.

Besides the risk of fire, the hazard of water damage is seriously increased by these openings. Floors should be

water-proof, and so arranged that the surplus of water may not pass down an opening to the injury of the floor or contents below.

Subdivision of the floor area by partitions reduces the hazard very materially. Partitions act in three ways: they confine the fire; they keep it back from the floor openings or draft areas; and they diminish the rapidity of spread, giving time for assistance to arrive. Partitions that are not fire-proof are valueless and increase the hazard by preventing close approach to fight the flames and by the cost to replace. Wooden studs covered with metallic lath and plaster are not to be treated as fire-proof. Such partitions may withstand a fire, but are liable to damage to an extent as to require renewal, since the wood chars beneath the plaster and lets the nails pull out.

Partitions should not rest on wooden sills or flooring, but be built on the arches and extend to the bottom of the arches above. This precaution is often neglected. Partitions should be solid, with as few openings as possible, in order to be most effective, as openings cut for doors and transom lights decrease their value as a fire retardent.

Comparisons have been drawn between fire partitions and brick walls. It is not reasonable to expect that partitions made of 2 inches of concrete plaster on expanded metal, or of 4-inch terra-cotta blocks, can withstand the same severe punishment as a 12-inch brick wall. Both fire walls and partitions have their legitimate duty to perform, and the inspector should not underrate the hazard by mistaking the one for the other.

Fire walls are especially valuable. Buildings covering a large area should be divided by such walls. If there had been some such division in the Windsor Hotel, the building could have resisted much longer. Every one has noticed how a thin brick wall will remain standing, even though a building be gutted and every floor falls. A thin party wall will hold a fire and prevent its spreading. Curtain walls, carried on the metal "cage" frame, are not as reliable as self-sustaining walls of equal thickness.

Combustible contents must be expected, but the quantity

of combustible material in the trim and finish of a building, and the manner of its application, directly affects the hazard. The amount of wood used in an average so-called "fire-proof" building having wood flooring, base, chair-rail, door and window-trim, amounts to about 2 pounds for each cubic foot of contents, without including the furniture or movable fittings. This would exceed the weight of the metal in a skeleton frame and be equal or nearly so to that in a cage frame. Without injury to the usefulness or efficiency of a building, the amount of combustible material could be reduced by careful planning. The wood floors could nearly all be left out, or, if retained, used only on limited areas and laid thin and solid on the concrete filling. An air space under flooring should never be allowed, as it is extremely hazardous. Nearly all the door and window-trim can be made of adamant plaster, and the only wood required would be for jamb and lintel. As the edges of partitions are always rough, the carpenter usually puts on the trim with an air space behind it. This air space should be filled with absolutely incombustible and permanent material.

Bases and chair-rails are useless ornamentation, and their value could be better utilized in some form of real fire protection. It is not necessary to use wooden studding for nailing purposes, as nails will take a firm hold in terra-cotta. In general, all woodwork should be omitted except where absolutely necessary, and then used on the slow-burning principle.

Windows are dangerous because they let a fire enter from without, and supply air and draft to a fire within. In consequence, they should be as small in size and as few in number as the circumstances will permit. They should be protected with shutters. When shutters are not feasible, wired glass should be used, and in exposed positions the glass should be doubled, with an air-space between. There is no reason why wired glass cannot always be used for windows on elevator and stair wells, and for door panels and transom lights. Wired glass has one advantage over shutters, in the fact that windows are less likely to be left open.

The main parts of buildings should be made self-supporting, no matter what happens. Heavy weights, such as tanks, elevator appliances, cornices, balconies, and the like, should be so constructed as not to fall, except in cases of total destruction. The hazard from falling weights is most serious in impeding the firemen, in breaking openings through the floors which would act as draft flues, and in damaging parts of the structure which would otherwise have been uninjured.

Smoke flues cause an annual loss to the insurance companies doing business in the United States of upwards of $20,000,000. In modern tall buildings, however, the hazard from these flues is reduced to a minimum, on account of the manner in which such buildings are constructed.

Expansion and contraction cause hazards which cannot be neglected. Every material used in construction expands on the application of heat, and the amount of expansion is not uniform. In composite construction—that is, where part is metal and part stone or brickwork—the difference in the lengthening of the various subdivisions in a tall building may be sufficient to create severe cross strains that may cause failure of certain details which otherwise would have withstood the heat. In many fires, external and fire-division walls have been thrown down by the expansion of the main metallic members. The design should provide allowance for expansion in all parts where the amount of lengthening would cause damage or failure.

There can be no question but that there is a hidden hazard in metallic members subjected to rust. Rust is a process of slow combustion, and, if allowed to progress, will eat away the members to an extent that may render them so thin as to heat rapidly, or to fail under a normal load. Metallic members, therefore, buried in masonry cannot be considered as safe as those which are located away from such masonry and protected with some good fire-retarding covering, which could be removed from time to time for the purposes of inspection.

In a broad sense, there are two separate methods of construction—one of them monolithic in character, the

other built up of small pieces, joined or cemented together by some different substance. Monolithic construction has the great advantage of solidity and uniformity, and from it small pieces are not apt to fall or break out, thus forming draft areas or flues. On the other hand, the financial hazard of such construction is great, for, if any damage is created, a greater quantity of good material must be taken out and replaced than if the construction were made up of smaller pieces.

A building of the Walker Soap Works, in Allegheny City, was exposed to fire on May 25, 1899. The fire occurred in a brick building 14 feet away, and for the time was very intense. The building was built of steel framework, filled in with cement walls, retained on expanded metal. The construction was monolithic, and withstood the heat with but slight injury, although the brick building was greatly damaged.

One of the most serious troubles is the alteration of the plans after the work has been started. The original design may call for a well-protected building, but, through carelessness of inspection or the desire to save a little money, the character of the building may be changed to a veritable fire-trap.

The question naturally arises whether it pays the owner to make a building thoroughly fire-proof. Unfortunately, there are many who build for the specific object of obtaining the greatest income from a minimum outlay, and the effort to save on the first cost is so great as to render their judgment valueless as to what should or should not be done. Tall buildings of cheap construction are a menace not only to owners and tenants, but to the community. In any building there must be, and always will be, an amount of combustible matter that cannot well be reduced.

Owners frequently locate floor openings so as to take up a minimum floor space, and thus render a maximum area available for income-earning purposes. Nearly every builder estimates the amount of space devoted to public use, and concludes that the best building is the one that has given up the least percentage. While this effort is

commendable from a purely income-earning standpoint, it often renders the design dangerous to life and property, and frequently makes it impossible to design a building under such conditions that shall be fire-proof. When stairs and elevators are placed together in the same well, there must always be a strong tendency to cut off means of escape and means of saving property from floors above.

Even in a fire-proof building dependence must be had upon human aid; and when the building is tall, it towers beyond the reach of any fire department.

A fire in the lower part is easily accessible, and the hazard most dreaded is that of a fire in the upper stories. The water tanks as usually supplied on roofs of tall buildings are inadequate in capacity. Unless the pumping plant of the building be so situated as not to be injured or rendered useless, the tank hardly pays for its cost in cases of severe fire.

Owners do not hesitate to spend thousands of dollars on fancy marble panelling, architectural carving and similar ornamentation, and will refuse to spend a few hundred dollars to have plans properly prepared and to see that the dangerous parts are constructed with that care which a really fire-proof building should demand.

From the viewpoint of the fire insurance companies, it appears as if such companies had no interest in actual fire-proof construction. Such should not be the case, for anything that will tend to reduce the fire hazard will necessarily tend to reduce the fire loss. The gross business of the companies might be reduced, but the net income would be increased. Unfortunately, they do not act in unison, and each one seeks risks which are dangerous in character, through a sheer spirit of competition. The influence for good that could be exerted by insurance companies is great, provided they would properly classify their risk, charging penalties or reducing their rates in accordance with the elements of design and the means employed to secure really fire-proof construction.

CHEMICAL SECTION.

Stated Meeting, held Tuesday, November 21, 1899

THE INFLUENCE OF SCIENCE IN MODERN BEER BREWING.

By FRANCIS WYATT, PH.D.,
Member of the Institute.

It is only fair for me to assume that the majority of you have given very little attention to malt liquors from the standpoint of their industrial production. You are, however, all well aware that beer is one of the oldest alcoholic beverages known to man; and that its age can be traced backward and backward until its history is buried under the *débris* of antiquity. It must have been the most popular beverage in Egypt some 500 years before the Christian Era, because Herodotus describes its qualities and says that it was made from barley malt; and that Isis, wife of Osiris (Rameses II, 1960 B.C.), was the mistress of the art of brewing. Diodorus Siculus, Plautus, Pliny, Strabo, Tacitus and Virgil all make frequent references to barley wine; and we know that the Romans did their best to promote the art of brewing in Britain. In the laws of Ina, king of Wessex, regulations are provided for the sale of beer, and the ancient Danes and Germans were as famous as their descendants still are, for brewing, as well as for drinking it. In comparatively recent times, Edward, the Confessor of England, was much addicted to spiced ale; and Henry III enacted a law fixing the price of malt liquor in cities at 1 cent per gallon, and in the country districts at the same price for 2 gallons. During the reign of Queen Elizabeth, the use of beer by all classes was so popular and general that a quart of good ale for each meal was the usual allowance for each individual. In the year 1690, when the amount of beer produced and sold by the licensed brewers of London amounted to a little more than 2,000,000 barrels, it was

made the object of a tax by the government at the rate of 60 cents per barrel; and as a mere evidence of the effect of taxation upon its comsumption, and the way in which history repeats itself, it is very interesting to note that when, in 1692, the tax was doubled, the consumption of beer fell off to 1,500,000 barrels.

In the United States of America there were in the year 1810 about 130 breweries, and their total product was a little less than 200,000 barrels per annum—all ale or porter, and all brewed on the time-honored plans of the English. In 1842 the manufacture of lager beer was introduced from Germany, and in 1850 the total production of malt liquors had risen to 750,000 barrels. In 1863 this had increased to 2,600,000 barrels, and until that time no record can be found of any interference on the part of the scientist. On the contrary, the utmost simplicity of method and ignorance of science everywhere prevailed, as may be gathered from the following quotation from a memorial which was officially presented to Congress by the United States Brewers' Association, as a body, in the year 1865, in connection with the determination of the proper method of collecting the governmental tax on fermented liquors:

"It may not be out of place to call your attention to the peculiar characteristics of the brewing business, and the circumstances which determine the marketable value of beer. To those practically acquainted with the manufacture of malt liquors, whether ale, porter or lager beer, we will be sustained in the opinion that in scarce any other branch of manufacturing are there so many obstacles to the production of a marketable article as in that of malt liquors. Limited as the brewer is to the use of barley for the manufacture of his malt, and to hops for which (as a pleasant and aromatic bitter and preserver of his perishable commodity) there is no substitute, though wet harvests may have rendered the former unsound, and unpropitious seasons impaired the strength and value of the latter, he is compelled to use them. To unsoundness in the grain and the blight of the hop (which has so alarmingly manifested itself for the last few years in the agricultural districts of

this country, and the consequent difficulty of obtaining a sufficient quantity of the best qualities to insure the keeping of the beer for any length of time) are mainly attributable the losses of the brewer, which, in this country, have been in some years so disastrous as to cause bankruptcy in many instances. An eminent and long-experienced and established brewing firm of England had not less than 20,000 barrels of beer returned to them by their customers in one year as unsalable. The sudden atmospheric changes ofttimes impair the quality of the beer. Unavoidable exposure, in transporting it from the brewery to a distant point of consumption, to severe cold, destroying its briskness and rendering it vapid and unpalatable, or to the summer's sun, which may cause acidity and the bursting of the casks, contribute to the disappointments and heavy losses to which the business is liable."

It will be seen from this that, despite its antiquity, brewing had made but little progress, and the working brewers themselves were in a state of the profoundest darkness. The product was, at the most and best, uncertain in all those qualities by which a beverage earns the title to be regarded as a food by the people. Nor is this in any way strange, for what can be expected from any industry conducted in ignorance of its elementary scientific principles? While an art is shrouded in mystery or practiced by secret methods; while there is no intercommunication of an intelligent nature between fellow-craftsmen, how can progress be expected? how can uniformity of product be realized? or how can the commercial operations connected with it be conducted without loss? I might cite innumerable instances—and so, I am sure, might you all—where strictly practical men, working on rule-of-thumb lines, without the least philosophical reasoning as to the why or wherefore of their processes, nevertheless have succeeded in doing excellent work according to their lights, and in furnishing products more or less answering to the public demands. So long as no change was rendered desirable by expediency or alteration of public taste, all would go well; but, directly the long-trodden path was abandoned, directly there was a

modification of raw material, or an alteration in the arrangement of the plant, or a desired change in the quality of the product itself, these same workers were beset by difficulties which they had no means of combatting, and which they could never overcome. Could none of us call to mind, at this moment, industrial establishments which were once at the height of prosperity, the glory of their environment, which commanded the highest market prices for their products, and enjoyed the uniform preference of the world? Where are they now? Have they sunk into insignificance or oblivion? Why, if not by reason of an intelligent and increasingly scientific competition, with which they were totally unable to cope?

If we look into the manner in which the brewing of malt liquors developed into a trade, and how, from a mere "art and mystery," it has developed into a science, we shall find that the condition of affairs which now prevails has been brought about solely by the development of scientific, not to say strictly chemical, knowledge. Do you suppose the ancient brewer knew anything whatever about his raw materials? Had he, do you think, any other reason than tradition or custom for any of his manufacturing processes? He was, I take it, absolutely blind to the phenomena of plant growth and of fermentation. The home-brews were made in the kitchen, or in the wash-house kettle; and from the meager accounts at our disposal, I gather that, up to within sixty years or so ago, even those beers which were brewed for sale in breweries established for commercial purposes were produced in so crude a way that very little difference in quality can have existed between the brews of Betty, the cook, and of Jones, the public brewer.

One thing is certain: What the malt liquors of those days lacked in other qualities they made up in alcoholic strength. In the light of our present knowledge, we can see that this excessive quantity of alcohol was essential to their stability; and was, in fact, the only means that could guard them against decomposition or undue acidity. They were dark in color, and necessarily very intoxicating; and they were probably well adapted to the needs of an older

and more athletic civilization. They would certainly not have suited an age of nervous, excitable, restless and overworked people, who live up to the doctrine of the "survival of the fittest," and are compelled to adhere to the laws which accord all the prizes in life's battle to the swiftest and the strongest. As I understand it, such a people as the latter require a beverage that must be nourishing as well as slightly stimulating; and which can only find complete favor on condition of possessing many additional qualities that appeal at once to the epicure and to the modern esthete. The half-sour, muddy and intoxicating ales or beers of our ancestors were naturally doomed to disappear or to fall into disfavor along with the manners and customs of their times, and their disappearance was hastened and facilitated by the practical applications of modern scientific education. This, I suppose, has been the course followed by nearly every industrial product of any importance throughout the civilized world; but in the case of the brewer it has not been followed in gigantic strides, but rather by a very slow and tortuous process of natural evolution, which has always been discouraged by his inertness. Time was, within my recollection, when practical brewers laughed at science, and scoffed at the scientist, but very gradually, and step by step, they have been brought to adopt the discoveries of science into their daily work; and so, unknowingly, and despite themselves, they are literally carrying on to-day, by "rule-of-thumb" methods, what I may with perfect propriety call the most intricately scientific processes of modern times.

Science schools and universities in all parts of the world have helped us along by fostering investigations of the laws which govern the fermentation industries, and I believe that there are few other branches of manufacturing which can claim to have enlisted the services, and to have enjoyed the discoveries, of more truly great scientists and disinterested investigators. An enormous amount of laboratory work has necessarily produced vast quantities of literature on the subject of fermentation and micro-organisms, in every known language, and it would be manifestly absurd

for me to attempt in one brief lecture anything more than a mere glance at the actual "influence of science in modern beer brewing."

The theory of modern beer brewing, as you will readily understand, is based primarily upon the results of a complete study of the nature of all the materials entering into the composition of beer, and of all the various microscopical fungus growths which, under normal conditions, cause the worts to undergo fermentation, or, when conditions are abnormal, bring about their spontaneous decay. The modern brewer must therefore be well grounded in science. He must be mechanic enough to know all about the structure of his complicated modern plant, the working of his various forms of pumps, boilers, engines, ice machines, etc. He must be an engineer and understand all about combustion, fuel consumption, cold production, efficient drainage and proper ventilation. Finally, he must have an adequate knowledge of chemistry and biology; and, in short, must depend upon science generally for the good qualities of his beer, and the maximum return from his materials. The prevalent fallacious notion among ignorant people that, if the production of beer is to be regulated by chemists, indiscriminate use of chemicals in its manufacture must follow as a natural consequence is, of course, absurd; the truth of the case being that we can only make real economies in any industry—and especially in the brewing industry—by discarding old-fashioned processes and faulty materials, in favor of processes and materials that will increase the output of the plant without any corresponding increase in machinery, labor or storage capacity. In every great industry in the world the chief modern developments have been made in the direction of increasing production and lessening cost, while improving the article produced. This is in accordance with what we all consider to be natural and fair, and it should certainly enter into no man's mind to question or doubt its perfect propriety. When science found the means of making cheaper or better steel by eliminating some elements from, and adding other elements to, the original pig iron, no outcry was made about adulteration or inferiority.

The steel manufacturer of to-day sells his steel under guarantee that it shall conform to certain tests of strength and quality; and, providing that it does so conform, everything is satisfactory. The farmer who was hitherto only able to grow 12 bushels of wheat on his acre of land has been taught by chemistry that the reason for this is the poverty of his soil; but by manipulating that soil according to chemical formulæ, reducing this and increasing that ingredient, putting in some element that was lacking before, he succeeds in producing 30 or 40 bushels of wheat upon his acre. Has it not been said of this man that by producing two blades of grass where only one grew before he has done more good to his country than a whole host of politicians? I take it for granted that you admit all these truisms, and I may come at once to the essence of my subject.

The process of brewing always was and still is nothing more nor less than the art of preparing an alcoholic drink by the fermentation of prepared cereal grains. As known to and practiced by us to-day, it is divided into two main operations:

(*a*) Chemical, and

(*b*) Biological.

(*a*) In malting a certain proportion of barley, in order to cause its germination, and to thereby produce the required changes in its composition. When this malt is finally ground and mixed with water at proper temperatures, its soluble constituents go into solution. This solution is then boiled with hops, and, when sufficiently concentrated, is cooled down to the desired temperature.

(*b*) In fermenting this boiled, cooled liquor by mixing in with it a certain quantity of beer yeast (Saccharomyces cereviciæ). When the fermentation has come to an end, the fermented liquor is stored in vats in properly-constructed cellars until sufficiently mature for consumption.

Looking at these operations as thus outlined, the brewing of modern beer would not appear to the uninitiated to be a very intricate operation, and would probably offer no startling aspects of revolution or novelty to the brewer of 500

years ago. I am, however, going to prove to you that whereas our ancestors were groping in the dark, we are now enjoying the light of science; and where they were working haphazard, we are now working on such scientific principles that we can, when we commence to make a brewing, foretell the kind of beer we are going to produce with scientific accuracy. I have already shown the great trouble with the old brewers—and even with comparatively modern ones who adhere to old ideas and methods—by reading to you an extract from their own petition to Congress in the year 1865. Their beers became cloudy and formed voluminous deposits within a very few days after being placed upon the market, and rapidly became acid, unpalatable and unwholesome, owing to processes of secondary fermentation and spontaneous decay. The only known means of partially overcoming these defects was to arrange for great alcoholic strength.

When chemists came into the field and commenced their investigations on the brewer's behalf, they very soon proved beyond discussion that these defects were due in every case either to naturally faulty or ill-made raw material, or to defective processes of treating that material during the mashing process; or to the impure character of the yeast; or to the impure nature of all conditions surrounding the brewing premises. The various wild yeasts and bacteria which constantly swarm in the air and infest all liquids which are exposed to their ingress fed upon the excess of proteid matter which all these old-fashioned beers necessarily contained, and decomposition, or putrefactive fermentation, invariably ensued, even in cases where an abnormal amount of hops had been used, and where a large proportion of alcohol to act as a preservative had been produced.

I have stated that the essential constituents of all malt liquors are derived from the chemical transformations of starch. These constituents are alcohol, unfermentable extract and carbonic-acid gas. The most precious qualities of all malt liquors—flavor, odor, brilliancy, stability and healthfulness—are chiefly attributable to pure and healthy fermentation.

Of the various cereals now used in the production of

modern beers and ales, the following is the average composition:

	Malt.	Corn Grits.	Rice.	Barley.
Moisture	4·00	10·50	10·60	12·00
Starch, sugar and gum	68·00	76·40	81·00	60·00
Fat	2·25	0·65	0·10	2·50
Nitrogenous matters (soluble)	4·00	0·00	0·00	0·00
Nitrogenous matters (insoluble),	8·00	11·00	7·20	12·00
Mineral matters	2·25	0·45	0·90	2·50
Cellulose or husk	11·50	1·00	0·20	11·00

From a superficial glance at these materials it would seem that the difference between the composition of the raw grains and the malt, as exhibited by my figures, is so extremely small as scarcely to demonstrate the utility of so costly and tedious an operation as malting. We must remember, however, that there are numberless phenomena constantly occurring in nature, productive of very familiar effects, which it would be impossible to explain on the basis of an analytical tabulation, and to this kind of phenomena the transformations in malt belong. The substances classed in the analysis of raw barley as nitrogenous, for example, are almost entirely insoluble in water. In my analysis of malt, on the other hand, it is shown that one-third of these nitrogenous bodies are soluble; and hence it is evident that they have undergone hydration during the malting process, and have been thus degraded to a lower and more assimilable state. It is these soluble nitrogenous matters, of which diastase is one, that form the basis of the mashing process; and it is they which cause the series of chemical changes which take place in the mash-tub.

It is not necessary to go into details concerning the very complex chemical composition of diastase, and I shall be satisfied with the statement that, under suitable conditions of temperature and moisture, it will convert many times its own weight of starch into sugars and dextrines; and that consequently the composition of a well-prepared brewers' wort is made up of the following substances, in variable proportions:

Maltose;
Malto-Dextrines;
Dextrines;
Albuminoids or Proteids; and
Mineral Salts.

Now, one of the first things that attracted the attention of chemists was the fact that all malts of good quality, and especially such of them as have not been subjected to too high a heat during the mashing processes, contain much more diastase than is needed to hydrolize their own starchy materials. This fact led to the formulation of the following proposition:

(*a*) The starch of the grain is the substance from which beer worts derive their main constituents.

(*b*) The starch of malted barley is in all essential respects identical in composition with the starch of raw barley and all other cereals.

(*c*) The diastase of malt is capable of converting much more than the quantity of starch with which it is associated.

(*d*) The chief troubles in finished beer are occasioned by the excessive quantity of nitrogenous bodies that pass into permanent solution in beer worts, made from malt and hops only.

This proposition, having been put to the test by practical experiment, has demonstrated that it is expedient—and indeed essential—to combine with malt a sufficient proportion of outside starch, in the shape of raw cereals, to more completely utilize the diastase; and, at the same time, by creating a greater mass of material, to diminish the proportion of alterable proteids.

Another factor of prime importance in all brewing operations is the nature and quality of the water supply.

This determination of purity or unfitness, of course, falls to the lot of the chemist-biologist, and it will not be amiss to glance at the qualities which distinguish good from bad water for brewing purposes.

The general objects which a chemist has in mind when he is called upon to examine a brewery water may be thus stated:

(1) Is it adaptable by its hardness or its softness, or its organic purity, for the general purposes of malting or brewing, or boiler feed? Or,

(2) Does it contain any organized or unorganized poisons

which would make it deleterious to the process or the product?

Not only must waters of bad taste and smell and carrying considerable amounts of foreign matters be rejected, but many others which are not only agreeable to the taste, but colorless, odorless, and containing very little suspended matter, are often the abundant sources of disaster and faulty fermentation.

The complete analysis of a brewing water, after it has been freed from insoluble suspended matter, should show how much it contains of the following elements:

(1) Hardness before boiling.

(2) Hardness after boiling.

(3) Total solid residue after evaporation.

(4) Residue after calcining the above at low red heat.

(5) Bases and acids.

(6) Free ammonia.

(7) Albuminoid or organic ammonia.

(8) Oxygen required to oxidize the organic matter in five minutes at 80° F.

(9) Oxygen required to oxidize the organic matter in three hours at 80° F.

(10) Nitrous acid or nitrites.

(11) Nitric acid or nitrates.

The salts that are most looked for, because the most important in a brewing water, are the sulphates and carbonates of lime, magnesia and soda, and the chlorides of sodium and potassium; and it may be here broadly stated that the combined total quantity of the earthy sulphates and carbonates should never exceed a maximum of, say, 100 parts per 100,000. I make this statement from my own practical experience in the laboratory and the brewery, and base it on a careful observation of the following facts:

(*A*) The sulphates and carbonates of lime and magnesia in the water interact upon the soluble mineral matters contained in the malt, and produce insoluble phosphate salts, which are left with the spent grains in the mash-tub. This, of course, unduly restricts the mineral food of the yeast.

(*B*) When the proportions of sulphates and carbonates

of lime and magnesia are greater than a maximum of 100 parts per 100,000, they have too great a deterrent action upon the formation of soluble nitrogenous matters during the malting process. They also unduly neutralize the required acidity of the worts, decrease the yield in total extract obtainable in the mashing process by from 5 per cent. to 6 per cent., exercise too great a restricting action on the diastase of the malt, and somewhat retard the final attenuation and clarification of the beers.

The salts which are of very rare occurrence, but which should always be the object of careful research, are those of such metals as copper, lead, zinc, chromium and iron, and all samples of water which contain anything more than the merest trace of any save the last-named should be condemned. When the iron in a brewing water does not exceed half of 1 part per 100,000, it has been proved that no evil effects are produced on the beer; but when it exists in larger quantities than this it becomes highly objectionable from its faculty of forming hop-tannates of a dark and disagreeable color and taste. It is best got rid of by aeration and precipitation as red-oxide, or by boiling, and adding a small quantity of powdered chalk.

It must be remembered that some single factor, resulting from the purely chemical analysis of water, may be altogether abnormal, and this, of course, is attributable to our lack of direct methods of investigating organic matter. The difficulty of interpretation is rarely caused by excess of chlorine or of the mineral salts, but is invariably to be found in the inconsistency of one of the numbers found either by the "oxygen" or the "ammonia" methods. The necessity for evidence of a kind which analytical tests alone are unable to supply is, therefore, manifest; and this evidence we seek by means of the microscope. To put it more plainly, wherever there is room for serious doubt as to the organic purity of a water to be used in a brewery, it must be examined biologically, and the vitality and nature of the micro-organisms contained in it must be made the gauge of its fitness or unfitness for use.

This bacteriological examination of water is fortunately

not a complicated operation, and can be conducted in a very simple manner. For all practical purposes it is merely necessary to mix a measured quantity of it (usually 1 cubic centimeter) with a proper sterilized, nutritive solution, in vessels protected from the air. This mixture is kept at a uniform temperature, and the microbes will soon have attained a sufficient development to be counted under the microscope. In my own laboratory I adopt malt wort as the culture medium, after it has been sterilized by boiling it in Pasteur flasks. The subsequent entrance of outside germs is prevented by closing the openings of the flasks with plugs of sterilized cotton wool as soon as the boiling is finished, and the wort preserves itself indefinitely after this without losing its brilliancy or undergoing the slightest change.

The water to be tested is well shaken up to insure perfect homogeneity, and 1 cubic centimeter of it is introduced into one of the sterilized wort flasks by means of a pipette sterilized in a gas flame. The flask is kept at a uniform temperature of 80° F. for three or four days; the behavior of its contents is very carefully and constantly watched, and a drop is taken out from time to time, in order that the development of micro-organisms may be examined under the microscope. As the operation is always conducted on exactly the same lines, it yields most useful and reliable data. If a water develops very active fermentation and very large numbers of organisms in the flask, we have undoubted proof of the existence of various species of bacteria, which are liable to cause trouble in beer; and this evidence must be taken as sufficient to forbid its use.

The fact that waters of medium permanent hardness are the best adapted for the production of the modern type of malt liquor has been established by experience, and is now very generally admitted by all those who have knowledge of the subject. It does not necessarily follow, of course, that good beers cannot be produced from relatively soft waters, or that any water which is good enough to drink is not good enough for the purposes of brewing. What I mean is that a large number of soft waters which have been used, and

are still being used, for brewing, and which are quite good and pure as they stand, may be vastly improved as beer-makers by the addition of certain hardening salts in moderate proportions.

When the chemist has finished with the water, he comes naturally to the barleys used for the production of malt, and here I may state broadly that the quality of malting barley mainly depends on the nature of the soil and the climate in which it is grown. Cold clay lands are unsuitable for its growth, and a warm, friable, calcareous loam is the best natural soil.

The essential qualities of malting barley are *vitality*, *condition*, *maturity* and *odor*. By vitality is understood growth capacity; and all barley designed for malting purposes should contain a minimum of non-germinating grains. In order to test a barley for its growing capacity we use what is known as the "germinating apparatus." This consists of a receptacle for water, a germination tray, and a felt cover, fitted with a thermometer. The corns to be tested are placed on the germinating tray and the necessary moisture for germination is derived from evaporation of the water in the receptacle underneath. In this way excess of moisture is avoided. The tray is constructed to hold exactly 100 corns, and, if the germinating capacity is uneven, the non-germinating corns can be perceived and counted.

It is customary to collect and classify all the nitrogenous bodies present in barley under the general term albuminoids. Very little is really known with accuracy as to the changes which these nitrogenous bodies respectively undergo during germination of the grain. Some of them become soluble in cold water; others do not. Of those which are soluble in cold water, some are coagulated by heat at temperatures varying from 105° F. to 212° F. Diastase belongs to these soluble, coagulable albuminoids, and so does peptase, which has been found to have an action on the albumens of the barley during the malting process similar to that of diastase upon starch.

One of the main objects in malting, in fact, is to induce the changes in the nitrogenous constituents of barley. From

the first moment of germination peptase begins to work. The insoluble nitrogenous substances acted upon by it become soluble. As fast as this solubility is effected, some of them are transformed into certain non-albuminous crystalline substances soluble in water and highly diffusible, known to chemists as amides.

For brewing purposes it is generally understood that a barley rich in albuminoids is not the best for malting purposes or for the production of sound beer. A malt rich in albuminoids is always low in percentage of starch. The wort resulting from such malt is poor in saccharine matter, and the finished beer is generally cloudy and unstable.

In regard to malting, the aim of the modern maltster is not to produce the most perfect development of the barley germ, and thereby the most flourishing and productive plant, but to simply develop sufficient vital activity to realize the required transformation uniformly throughout the entire mass and at the least possible expense of material, time and money. A certain quantity of water and a certain degree of temperature bring the embryo into activity. It commences by secreting those substances which are capable of reducing its food to an assimilable condition. The diastase, which transforms the starch into sugar, is thus formed; the insoluble albuminous matters, which could not be diffused through a membrane like the yeast cell, are acted upon by the peptase and transformed into peptones and amides.

The maltster allows the embryo to act upon the endosperm sufficiently to prepare the latter as its food, but he does not allow it to consume the food after its preparation. We do not require a maximum development of the germ. We are careful not to use optimum temperatures, and we seek for that point at which the transformation may go on equally well throughout the innermost parts, and stop when that point is reached.

The kilning of malt after germination is finished does not imply a simple desiccation or drying of the germinated grain. Its object is not merely to definitely stop the growth and confer keeping qualities, but to bring about certain

chemical transformations which will enable us to brew a healthy, palatable and stable beer of any desired color, taste or smell. A good malt must be perfectly well cooked. It must yield a high amount of extract, and the worts that run from the mash-tub must be brilliant and stable.

Too high an acidity in a malt may in many cases result from a primitive defect in the unmalted grain, but more generally it results from unskilful malting. A very high percentage of acidity in malt generally produces a complete disturbance of the albuminous constituents of the wort, and the ratio of the so-called peptones and amides is considerably and disadvantageously modified.

A good malt cannot be too friable; it should be so crisp that a grain taken between the finger and thumb should be easily crushed, the inside portion falling from it in a fine, granular powder. There are two things absolutely necessary to obtain a good malt: A very complete disaggregation of the entire substance of the grain during the steeping, and a very slow drying on the malt-kiln at a very low initial temperature, combined with a very free circulation of pure air. The first temperature on the kiln must be about 100° F., with a very great draught; the second, about 130° F.; the third, about 150° F., and then we may go to 180° F., with the air shut off, or as much higher as may be necessary, according to the quality of malt desired. These temperatures have been fixed by chemists, and they are based on sound, scientific principles. If we pass a measured volume of air over any damp or wet body, we find that the air will take moisture from that body until the point of its saturation has been attained. The point at which air becomes saturated with moisture depends, as you very well know, upon the temperature of the air itself. The hotter it is, the more moisture it will take up. Consequently, the wet or green malt might be dried very rapidly by very hot air, but this is what we want to avoid, especially at the beginning, for if we dry too quickly, we shall dry from the surface inwards, whereas what we must aim at is to so regulate the temperatures and the volume of the air as to commence the drying from the inside outwards, gradually

increasing our temperature as the operation approaches completion. The higher temperatures employed in finishing off the malt on the kiln undoubtedly determine its quality and general character, and we may produce at will malts that are known as pale, brown and black and medium and high-dried. From a practical point of view, the utmost advantage and economy result from using high-grade, high-dried malts in brewing. They give a pale beer and possess excellent diastasic power. They favor to the maximum the reproduction of yeast, and secure a very desirable degree of fermentation.

Of all the bodies contained in malt, diastase is the most sensitive to the effect of heat and moisture, and this is a point which chemists have now succeeded in impressing upon all maltsters and brewers. It has been demonstrated to them in practice that the kilning process undergone by malt has a diminishing influence on diastasic activity, and I will give you a few figures to prove this:

Temperature.	Moisture.	Diastasic Power.
140° F.	7·00	168
150° F.	5·00	145
160° F.	4·20	120
175° F.	3·10	105
190° F.	2·05	87

Speaking in a general way, a given weight of green malt taken from the germinating floor will generally exhibit the same amount of diastasic power as the same weight of a well-made, well-kilned malt fresh from the kiln. The green malt, however, contains from 40 to 50 per cent., by weight, of water, and thus a great portion of the diastasic power is naturally seen to have been destroyed during the kilning. The amount of destruction varies in proportion to the quantity of water, and there is no doubt that in this respect diastase shows itself to be akin to all the other albuminous substances that have been investigated. The protoplasm of the microbe cell will stand without injury an amount of dry heat which would immediately overcome it were the heat to be suddenly charged with moisture. To sterilize a solid body of the nature of starch would require a dry tempera-

ture of about 350° F., whereas in the presence of water or moisture a temperature of 212° would rapidly kill all germs. If we were to enter a room or chamber heated up to, say, 170° F., and devoid of all moisture, we should probably be able to walk about it pretty freely, but if we went into an adjoining room, heated to the same degree and containing an atmosphere saturated with water, we should find it impossible to remain even for a few moments.

It is generally admitted, and has been demonstrated by careful experiment, that the maximum saccharifying activity of diastase is exhibited at a temperature of 140° F., at which it has the power of changing gelatinized starch into four molecules of maltose and one double molecule of dextrine. This hydrolizing action does not take place suddenly, but occurs very gradually and by successive changes. It is believed to commence by breaking down the starch molecule into a molecule of free maltose, and a molecule of very complicated form, which we call malto-dextrine. This latter molecule, by continued action of the diastase, is broken down into free maltose—a less complicated form of malto-dextrine and free dextrine. Slowly proceeding in this manner, the ultimate conversion product is a maximum of maltose and a minimum of dextrine.

If, instead of being maintained at 140° F., the solution of diastase or the mixture of malt and water is heated at the initial stage to a high point—say, for instance, to 155° F.—the actual activity of the diastase is much increased, but its converting power is seriously lessened. It will still be able to very freely effect the transformation of starch, but the conversion products will not be the same as those produced by the lower temperature. They will consist of much less free maltose and much more complex malto-dextrines, as the final outcome. And this effect will be a permanent one and, when once produced in the mash-tub, will not be changed by any subsequent alteration of temperature. It follows from this that chemists have taught the brewers to use the utmost caution in attaining what is known in practice as the converting heat of the mixture of malt and water, because it is this converting heat that absolutely determines

the proportion of directly fermentable matter desired in the wort before it is mixed with the yeast.

Applying these facts to the process of saccharification in the mash-tub, we shall presently see that, according to the power of the diastase, and the temperature at which that power is developed, we may produce variable proportions of the products of starch conversion—maltose, malto-dextrines and free dextrines—and thus have a means of predetermining, with approximate accuracy, the character and composition of our beers.

Let me now turn for a moment to the use of those starchy or saccharine materials which are known as malt substitutes, or malt adjuncts.

The proportion in which these materials are used varies, of course, with different circumstances and conditions, and it is safe to say that it may range from 20 per cent. to 40 per cent.; the average, however, being about 30 per cent., by weight, of the total extract required in the brewing.

Large sums of money have been invested in this country in machinery to manufacture these materials, and their use has brought about a vast improvement in the quality of the beer brewed. They modify the malts, which vary somewhat from year to year, according to the season, and, speaking generally, accomplish the following objects:

(1) They diminish the percentage of alterable proteids in the finished beer, the presence of any excess of such proteids having an invariable tendency to provoke instability and produce cloudiness in the finished product.

(2) They give a pale color and more effectual and rapid clarification, and a softer and fuller flavor.

Rice, which is largely used by brewers on account of its high percentage of starch, and its freedom from soluble nitrogenous matters and oil, is a brewing material of the very first class.

Maize or Indian corn, from which our commercial corn grits, corn meal, flaked corn, etc., are obtained, cannot be used in its natural state in the brewery on account of the large quantity of oil which it contains. In order to fit it for brewing purposes in either of its various forms, it first

undergoes a somewhat intricate mechanical treatment. The whole maize is put through a mill which deprives it of its hull and of its germ, the germ being that portion in which the major part of the oil is contained. The kernel thus hulled and degerminated is passed through a series of knives or choppers, and the product is divided up into various categories, according to its fineness. Thus, hominy is the name given to the very coarse particles; grits are somewhat finer than hominy; and the fine flour is called meal. It must be noted that the large particles contain the least oil. Thus, for example, while the original maize generally contains on an average 5 per cent. of oil, well-prepared hominy does not contain more than 0·5 per cent. Well-made grits should never contain more than 1 per cent., while corn meal will generally contain from 1·5 per cent. to 2 per cent. In the course of preparing grits on a large commercial scale for the use of brewers, the millers find various sources of profit. For example, a very fine flour or meal is sold for cooking purposes. A somewhat inferior grade is mixed up with the powdered husk and sold as cattle feed. The separated germs are subjected to a treatment by which the oil they contain is extracted from them, this oil being a very valuable article of commerce, either for the purpose of food, or as a lubricant, or as an ingredient in the manufacture of the finer soaps.

Flaked maize and flaked wheat are both excellent brewing materials, and are made by first removing the husk and the germ and pressing the starchy portion between steel rollers in order to flatten it out and break it up. The flakes are finally dried by hot air. The great advantage of using prepared cereals of this nature is that they may be put directly into the mash-tub, together with the malt, and require no previous conversion in a separate brewing vessel.

Grape sugar and glucose have long been favorite brewing materials, and are both made by boiling starch with a weak acid. When starch is boiled, either with or without pressure, in presence of a weak acid, such, for example, as very dilute hydrochloric acid, it is rapidly hydrolized or transformed into dextrine and maltose. These, by further

boiling, are nearly entirely transformed into dextrose or grape sugar. When the desired transformation is effected, the hydrochloric acid is neutralized by carbonate of soda. Chloride of sodium is thus formed. The liquid is then passed through charcoal in order to bleach it, and is finally evaporated to any desired consistency.

In regard to the use of unmalted cereals in brewing, it must be borne in mind that their starch granules are contained in cells. These tiny cells must be ruptured before the starch can be acted upon by diastase. To effect the rupture of these cells, it is necessary to resort to gelatinization with hot water. In the case of malt it will be remembered that the process of malting partially liberates the starch by softening or dissolving the cell walls. The malt starch being thus rendered more sensitive to the influence of hot water, the comparatively low temperatures of the brewer's mash process are sufficiently high to effect its gelatinization. Very high temperatures are required, however, in order to free the starch granules of raw grain, and this is why when brewing with it two distinct mashing operations are performed. One of the operations consists in boiling the raw grain itself for a sufficient length of time to render the starch available; the other operation consists in mashing the malt at a low temperature and thus preparing the diastase to act upon the starch of the raw grain when the two mashes are brought together in one tub.

As a matter of actual practice, it is calculated in the brewery that 1 bushel of malt in a brewing may be replaced, so far as available extract is concerned, by:

$27\frac{1}{2}$ pounds flaked corn.
$26\frac{1}{2}$ pounds rice.
$26\frac{1}{2}$ pounds grape sugar, or glucose.
29 pounds corn grits.

The hops used in beer brewing are the female flowers of the plant *Humulus lupulus.* The male flower is useless and the plant bearing it is never cultivated.

Average good, fresh hops are made up of from 7 to 10 per cent. of water; about 3 per cent. of tannin; some 10 per cent. of various mineral salts; 15 per cent. of albuminous

matter, of which one-half is coagulable by heat and made insoluble by the tannin; and about 10 per cent. of resins and essential oils and fats. These quantities, however, are by no means constant, and are found to vary as the hop grows older.

The tannin of the normal hop is entirely different, of course, from any other kind of tannin; and, in fact, appears to consist of two distinct varieties, one of which forms insoluble coagulates with albuminous bodies and yields a very pale green color when treated with ferric chloride, while the other is supposed to form compounds with albuminoids which are soluble in warm, but insoluble in cold liquids, and this variety produces a dark green color with ferric chloride. The value of these tannins is assumed to be confined, in the brewing process, to the formation of insoluble bodies from the coagulable compounds contained in malt wort.

As to the resins which are contained in the hop, they have been found to consist of three distinct physical varieties, but the individual qualities of each have not been thoroughly investigated and are very much in doubt. There is one of them which has a crystalline fracture and which, while it is quite tasteless in the solid form, becomes intensely bitter when dissolved in very dilute alcohol; but as a matter of fact, they are all three but slightly soluble in hot water, and appear to be thrown out of solution directly the water becomes cold. It has been stated by some investigators that all the preservative qualities of the hop are due to the resins, but I have found in my own practice that there are some ferments, and notably the acetic ferment, upon the growth of which the hops have no retarding action.

About one-half of the nitrogenous matter contained in hops does not coagulate when boiled, but goes into permanent solution in the boiling wort. This soluble hop albumen is easily assimilated by yeast and the plant thrives upon it perfectly. As you may very readily imagine, hops constantly vary in quality, in accordance with the climatic conditions of the year in which they are grown and picked. The chemist must, therefore, content himself, when a sam-

ple is submitted to him, with reporting upon the percentages of water and tannin, the condition and quantity of the lupulin, and the amount of extract yielded to petroleum ether, chloroform and water. If all these points compare favorably with established standards the sample in question may be expected to give good results in the brewery. No chemist can say, however, whether the hop is going to impart the desired aroma, or foretell whether it will or will not give some characteristic and undesirable flavor. When hops are quite fresh, we find the lupulin in the form of golden yellow globules filled with an almost colorless liquid. It becomes gradually darker with age, until it is finally brown. This transformation is invariably accompanied by a reduction in the percentage of the tannin, and by the production of valerianic acid, the disgusting smell of which enables its presence to be readily detected.

Having thus taken a bird's-eye view of the materials used by the modern brewer, it becomes necessary for me to acquaint you with those organisms or plants which induce alcoholic fermentation in saccharine solutions, and which are known under the general name of *Saccharomyces.* Under normal conditions they reproduce themselves by budding, and they have been therefore assigned to that division of the great fungus group known as budding fungi. In brewing technology they are described under the general term *Yeast.* Yeast cells are either single or occur in groups or strings; each cell consists of a thin-walled sac or bag, containing a semi-fluid matter, in the center of which there is often a space full of a more clear and watery fluid than the rest, which is termed a vacuole. The sac is comparatively tough, but it may be easily burst, when it gives exit to its contents, which readily diffuse themselves through the surrounding fluid. The whole structure is called a cell, the sac being the cell wall and the contents the protoplasm. Under a high magnifying power each cell is seen to be round or oval, and on the average about $\frac{1}{3000}$ of an inch in diameter. To the naked eye yeast appears as a thick, cream-colored fluid. If all the liquid be removed from the mass by pressure, the residue may be dried at a low temperature to a

powdery mass, without losing its vitality. When heated in the moist state to the temperature of boiling water, its fermentative power is completely destroyed. Fermentation which has already commenced in a liquid can be stopped by boiling it.

There are found to be associated with ordinary yeast in most fermentations and beers a great number of organisms of quite different appearance and character from the true beer yeast cells, and which may all be classed under the general terms wild yeast and bacteria. Chemists have proved most conclusively that these organisms give rise to the various diseases to which beer is subject. In other words, they induce fermentations in saccharine solutions which give rise to other products than alcohol and carbonic acid, and this has led to their classification according to the functions they fulfil or the products they engender.

When a minute quantity of pure beer yeast is added to some brewers' wort which has previously been filtered bright, the mixture, if kept in a glass flask at a temperature of about 70° F., soon becomes turbid and after a few hours gives off bubbles of gas which rise to the surface, the liquid becoming gradually more and more turbid. Later on, a sediment of yeast will be observed at the bottom of the flask. If the yeast cells be carefully examined under the microscope from time to time while this action is going on it will be noticed that at first the vacuoles which were present in every cell gradually disappear, each cell becoming full and rounded in appearance, owing to the absorption through the cell walls of certain nourishing substances from the wort. Some minute little buds will be noticed jutting out from the sides of the cells; these buds rapidly grow and soon assume the size of the parent cell, from which they finally become detached, but not before they, in their turn, have developed other buds, and these yet others, thus giving rise to those groups or strings of cells which are sometimes seen under the microscope. This cell reproduction and growth is due to the nourishment which the yeast derives from the wort, but for some time after the yeast cells continue to produce buds—and even after the

rupture takes place between the parent cells and the resulting daughter cells—the former still continue to absorb and assimilate various nitrogenous substances from the liquid.

It was long held that the only true theory in regard to fermentation was the one formulated by the distinguished Pasteur, which was, that:

"Alcoholic fermentation is a chemical action connected with the vegetable life of cells, which cells, in the absence of free oxygen, live by withdrawing the oxygen they require from certain carbohydrates, such, for example, as maltose or grape sugar."

Quite recently, however (1897), it has been shown by Buchner—a good authority—that the actual process of fermentation, or, in other words, the decomposition of sugar into alcohol and carbonic acid gas, is independent of the vital action, being induced *outside the yeast cells by a functional product excreted during its growth.* This product has been eliminated by Buchner and called zymase; and it is to all intents and purposes an enzyme or diastase.

[*To be concluded.*]

Mining and Metallurgical Section.

Special Meeting held Wednesday, January 31, 1900.

THE OCCURRENCE OF FULLER'S EARTH IN THE UNITED STATES.

BY DR. DAVID T. DAY,
Chief of Division of Mineral Resources, U. S. Geological Survey.

Characteristics.—The only classification of clays which suggests itself by which definite place can be given to the variety called fuller's earth would be based upon the consideration of the relative proportion of total bases, such as alumina, iron, calcium, magnesia, alkalies and silica, together with the proportion of water in the sun-dried clay. Very frequently the clays which have a large proportion of total

bases and silica usually contain more than the average amount of water. For example, kaolin, containing from 40 to 50 per cent. of silica, and from 30 to 40 per cent. of total bases, will frequently contain from 10 to 15 per cent. of water in the sun-dried material. Where, however, the percentage of silica is very high, say 70 per cent., and the total percentage of bases less than 30, the percentage of water is usually quite low. Fuller's earth appears to be an interesting exception to this rule, as its chief chemical characteristic seems to be a high percentage of silica, which, though varying through a considerable range, frequently reaches 65 to 70 per cent., but with a total proportion of bases even as low as 20 per cent., and seldom higher than 28 per cent., while the percentage of water in the sun-dried material will range easily from 15 to 25 per cent. Approximately half of this water can be driven off by prolonged heating in a water-bath; the remainder is only to be driven off at a much higher temperature. These clays usually stick to the tongue more than other clays. When placed in water they show no plasticity, but fall apart in gelatinous flakes.

Such clays have been used for very many years even in this country for extracting from newly-made cloth the oil used to render the wool pliable in weaving. From this fulling process the clay has taken its name.

Silliman refers* to a deposit near the town of Kent on the Housatonic River, in Connecticut. He states that: "A fuller's earth is a clay usually soapy in its feel, very absorbent of grease and oily matters; fine in its texture, so as to present no parts that shall be large and harsh enough to injure cloth or wool, mechanically, by rubbing; it should fall to powder easily in water, so as to diffuse itself through that fluid, and easily mix with it and with the stuffs to which it is applied. The fuller's earth of Hampshire, England, so much celebrated, is of a greenish-yellow, tolerably firm, crumbles easily in water, receives a polish from the finger nail, and is *very powerfully detergent*. This is, after

* *American Journal of Science*, first series, I, 2, 217.

all, the important criterion by which to distinguish fuller's earth: if it removes grease with avidity, crumbles easily in water so as to diffuse itself readily, and yet is not so coarse as to wear the fiber, it is fuller's earth. The subject is of some practical importance to this country on account of its woollen manufactures, which, although checked for the present, must eventually rise and prevail. While they are of small extent it may be better to use soap, but in very large establishments fuller's earth from its cheapness (provided it can be abundantly obtained) is very desirable.

"With respect to the existence of fuller's earth in the clay of the Kent iron bed it appears very probable, and some of the specimens appear very like the Hampshire earth, but experiments alone can decide."

This visit of Silliman was in 1820. William Thompson* found clay in a fullonica excavated at Pompeii, which was pointed out to him as the soap which the ancient inhabitants used. This was used not only by the washers and dyers, but frequently in the ordinary houses. In composition it has the general characteristics of fuller's earth.

One of the first uses for the white kaolin at Woodbridge, N. J., was for this same purpose of fulling cloth in the absence of real fuller's earth, as shown by note on page 1 of the Report on the Clay Deposits of New Jersey, Geological Survey of New Jersey, in 1878.

But the name fuller's earth has usually designated the material obtained in Surrey, England. This has been the chief source of supply for English cloth manufacturers and for export. Various attempts have been made by mineralogists to find in fuller's earth some definite mineral substance which could be referred to as distinctive and which could be found in all varieties. Thus, Dana speaks of it as being in part kaolin and partly the hydrous silicate smectite, but this has been of little value in the identification of other specimens. Even to-day the name fuller's earth is applied to any form of clay which has the characteristics

* Reports of the British Association for the Advancement of Science, **49**, 321.

mentioned above, and is capable of absorbing liquids in considerable quantity, and particularly when it will act like bone-black in taking out the coloring matter from certain oils.

Developments of the Industry in the United States.—For many years either soap or fuller's earth was used as a detergent in fulling cloth, but with the increased use of cotton-seed oil English fuller's earth came to be used to decolorize such vegetable oils and also lard oils. This increased the importation of fuller's earth very markedly, as shown in the table appended.

In 1893 good fuller's earth was discovered in the United States quite accidentally. At Quincy, Fla., an effort was made to burn brick from the clay found on the lands of the Owl Cigar Company; the effort was a failure, for fuller's earth when burned exfoliates instead of forming a coherent mass, suitable for bricks. An Alsatian cigarmaker employed by the company called attention to the close resemblance of this clay to the German fuller's earth. As a result, the material found sale and the industry was developed. This use quickly spread as a substitute for, though more expensive than bone-black, filtering various mineral oils, and it is principally for such purposes that the American earth is now used, the English earth being preferred for cotton-seed and lard oils. The development of the industry in this country was sufficient to develop a widespread interest in the search for fuller's earth, and thousands of samples were examined by the chemists of various consumers. Most of the clays examined proved worthless, yet enough good samples were obtained to show that the region to the west and north of Quincy contained many other available deposits if needed. The search extended over the United States, and deposits were soon found in Virginia, North Carolina, Georgia, at various places in Florida, Indian Territory, Nebraska, Colorado, New Mexico and South Dakota. A small industry has been developed in New York State, but, with this exception, the supply continues to come from the developed deposits at Quincy, Fla. The reason for this is the great variation in quality of the earth

from different deposits. That from North Carolina and Virginia is more or less sandy; that from Georgia is almost identical with the Quincy earth, but is not more favorably located for shipment. All the other deposits are less accessible, except one near Tampa, which promises soon to be a large source of supply. Curiously enough, the material produced in Florida bears little outward resemblance to the earth which has long been imported from England.

The earth discovered in South Dakota is almost the exact duplicate of the English earth in every respect, and will no doubt become a valuable substitute for it.

Fragments of chert are common in beds of fuller's earth, and in Georgia fuller's earth passes almost indistinguishably into layers of chert, with nearly the same color and fracture. At Ballert Point, near Tampa, Fla., the fuller's earth contains many oyster shells, bits of coral, etc., all entirely changed to chalcedony. This leads to the suggestion, as to the origin of this earth, that it is probably ordinary clay which has received from interfiltering solutions an additional supply of silicic acid which has sometimes combined with the clay, and occasionally has been deposited as chert.

The conditions of occurrence of fuller's earth and the manner of preparing it for market are quite simple. In Florida it may be found outcropping at the foot of slopes around the edges of the swamps. The clays appear to occur in large, shallow basins in the swampy tracts characteristic of the region around Quincy, and many other parts of the State. Usually there will be 1 or 2 feet of surface soil, then 2 to 6 feet of mottled, plastic clay, then the fuller's earth in layers varying in thickness from 2 to 12 feet, then a layer of sand mixed with fuller's earth, which is usually persistent for a considerable depth below the deposit. Occasionally a second deposit of fuller's earth, bluish in color, will be found below the first, with a layer of sand intervening. Up to this time the very simplest methods have been used in preparing it. The overburden of sand and worthless plastic clay is removed and the wet fuller's earth chopped out in thin slices with mattocks and allowed to dry in the sun for several days. By this means the wet, greenish clay will lose

PRODUCTION OF FULLER'S EARTH IN THE UNITED STATES FROM 1895 TO 1898.

Year.	Quantity.	Value.
	Short Tons.	
1895	6,900	$41,400
1896	9,872	59,360
1897	17,113	112,272
1898	14,860	106,500

IMPORTS OF FULLER'S EARTH FROM 1867 TO 1899.[1]

Year.	All Kinds.		Unwrought.[2]		Wrought.[2]	
	Quantity. Tons.	Value.	Quantity. Tons.	Value.	Quantity. Tons.	Value.
Ending June 30th.						
1867	280	$3,113				
1868	211	2,522				
1869	324	3,587				
1870	239	2,619				
1871	290	3,383				
1872	274	3,358				
1873	251	2,978				
1874	277	3,440				
1875	300	3,694				
1876	246	3,097				
1877	400	4,460				
1878	335	4,095				
1879	361	4,269				
1880	578	6,925				
1881	268	3,207				
1882	908	11,444				
1883	1,241	14,309				
Ending December 31st.						
1897[3]	—	—	2,308	$14,283	2,138	$20,037
1898	—	—	2,038	15,921	6,315	55,123
1899[4]	—	—	2,639	17,147	5,243	37,525

[1] Not classified from 1883 to 1897.
[2] Not classified separately until 1897.
[3] Latter half.
[4] Three-quarters of calendar year.

	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	H_2O.	Na_2O.	K_2O.
	P. C.	P. C.	P. C.	P. C.	P. C.	P. C.	P. C.	P. C.
Smectite from Cilly[1]	51·21	12·25	2·07	2·13	4·89	27·89	—	—
Fuller's earth from Reigate[2]	53·00	10·00	9 75	·50	1·25	24·00	—	—
Malthite from Steindörfel[3] . .	50·17	10·66	3·15	·25	—	35 83	—	—
Fuller's earth from England[4]	44·00	11·00	10·06	5·00	2 00	—	5·00	—
Fuller's earth from England[5]	44·00	23·06	2·00	4·08	2 00	24·95	—	—
Fuller's earth from England, No. 1 (blue earth)	52·81	6·92	3·76	7·40	2·27	14·27	—	·74
Fuller's earth from England, No. 2 (yellow earth)	59·37	11·82	6·27	6·17	2·09	13·19	—	·84
Fuller's earth from Gadsden County, Fla.[6]	62·83	10·35	2·45	2·43	3·12	7·72	·20	·74
Fuller's earth from Decatur County, Ga.[6]	67·46	10·08	2·49	3·14	4·09	5·61	—	—
Fuller's earth from Fairburn, S. D.[7]	58 72	16 90	4·00	4·06	2·56	8 10	2·11	
Fuller's earth from southeast of River Junction, Fla.[8] . .	50·70	21·07	6·88	4·40	·30	9·60	—	—
Fuller's earth from between Mt. Pleasant and Norway, Fla.[9]	58·30	10 63	6·72	1·71	3·15	9·05	—	—
Fuller's earth from near Norway, Fla.[10]	54·60	10·99	6·61	6·00	3·00	10·30	—	—
Fuller's earth from Valentine, Neb.	47·37	7·08	3·89	32·19	1·19	—	Trace	·93
Fuller's earth from Ocala, Fla.	36·73	27·78	3·21	·81	·64	At 110°, 7·38 Above 110°, 12·14	—	·42
Fuller's earth from Fairburn, S. D.	68·23	14·93	3·15	2·93	·875	6·20	—	—
Fuller's earth from Custer, S. D.	55·45	18·58	3·82	3·40	3·50	8·80	—	—
Fuller's earth from Custer, S. D.	57·00	17·368	2 362	3·00	3·027	9·50	—	—
Fuller's earth from Custer, S. D.	63·50	14·97	4·48	2·40	2·882	—	7·20	1·116
Fuller's earth from Custer, S. D.	71·28	14·33	2·484	·33	1·199	4·30	—	—
Fuller's earth from Hermosa, S. D.	55·40	27·70	1·80	2·30	·703	—	·487	·589
Fuller's earth from Fairburn, S. D.	60·16	10·38	14·868	4·96	1·714	7·20	—	—
Fuller's earth from Fairburn, S. D. (dried)	56·18	23·23	1·26	5·88	3 29	11·45	—	—
Fuller's earth from Fairburn, S. D.	67 00	5·00	12 00	—	—	15·00	—	—
So-called "Glacialite," Enid, Oklahoma Ter.	50·36	33·38	3·31	—	—	12·05	·88	

[1] Pogg. Ann., **77**, 591, 1849.
[2] Klaproth, Beitr., **4**, 338, 1807.
[3] Dana, System of Min., p. 695, 1893.
[4] Geikie, 1893, p. 133
[5] Penny Encyclopedia, **11**, Dr. Thompson, analyst.
[6] P. Fireman, analyst.

SO_3.	CO_2.	P_2O_5.	FeO.	TiO_2.	NaCl.	MnO.	Moisture.	Volatile Matter.	Organic Matter.[11]	Moisture in Air-Dried Sample.	Calculated to Water-Free Material (dried).
P. C.	P. C.	P. C.	P. C.	P. C.	P. C.	P. C.	P. C.	P. C.	P. C.	P. C.	P. C.
—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—
·05	—	·27	—	—	·05	—	—	—	—	—	—
·07	—	·14	—	—	·14	—	—	—	—	—	—
—	—	—	—	—	—	—	6·41	—	—	—	—
—	—	—	—	—	—	—	6·28	—	—	—	—
—	—	—	—	—	—	—	2·30	—	—	—	—
—	—	—	—	—	—	—	7·90	—	—	—	—
—	—	—	—	—	—	—	9·55	—	—	—	—
—	—	—	—	—	—	—	7·45	—	—	—	—
·20	17·73	·21	—	—	—	—	—	—	—	2·53	110 C.
—	—	5·54	—	1·27	—	—	—	—	3·61	—	—
—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	Trace	—	5·35	—	—	—
—	—	—	—	—	—	Trace	—	5·85	—	—	—
—	—	—	—	—	—	—	—	CO_2 & Vol. 10·70	—	—	—
—	—	—	—	—	—	Loss	—	Alk. und.	—	—	—
—	—	—	—	—	—	13·00	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	Org. Trace	—	TiO_2 Trace	—	—	—

[7] E. J. Riederer, analyst.
[8] Standard Oil Company's property. E. J. Riederer, analyst.
[9] Howell property. E. J. Riederer, analyst.
[10] Morgan property. E. J. Riederer, analyst.
[11] The organic matter is based on the assumption of Wolff that humus contains 58 per cent. arbon, the latter being directly determined.

perhaps 50 per cent. of its weight, turn to a creamy white color and become very brittle and easily split into thin layers. It then contains 15 per cent. of its weight of water, which can only be driven off above the boiling point. Lately artificial dryers have been introduced and an arrangement for grinding the earth to the requisite fineness. The process of levigating the earth, which is quite common in Surrey, England, is not used in this country at all. This Florida earth, ground to 60 mesh and finer, is used almost entirely as a substitute for bone-black in filtering mineral lubricating oils, although its use has extended to some extent for the lightening of the color of cotton-seed oil. But for this latter purpose the practice is still universal of using English fuller's earth which has been taken out by the ordinary method and then washed in long, narrow troughs, very much like hydraulic sluice boxes, allowing quite a large percentage of the material to settle out as sand and displace the lighter material which goes off into the settling tanks, in which it is finally dried and sold in the resulting lump form. The English earth has not proved any more suitable for the refining of mineral oils than has the American earth for use in vegetable oils. The common practice with the mineral oils is to dry the earth carefully after it has been ground to 60 mesh, and fill it into long cylinders, through which the crude black mineral oils are allowed to percolate very slowly. As a result the oil which comes out first is perfectly water-white in color and markedly thinner than that which follows. The oil is allowed to continue percolating through the fuller's earth until the color reaches a certain maximum shade, when the process is stopped, to be continued with a new portion of earth. The oil is recovered from the spent earth.

With the vegetable oils the process is radically different. The oil is heated to beyond the boiling point of water, in large tanks, to which from 5 per cent. to 10 per cent. of its weight of fuller's earth is then added, and the mixture vigorously stirred for twenty minutes and then filtered off through bag filters. The coloring matter remains with the earth, leaving oil of a very pale straw color, provided the

original cotton-seed oil had been sufficiently well refined by the ordinary process to admit of this, and provided the operation had been conducted with sufficient care. Perhaps the most remarkable feature of this filtration by fuller's earth is the different rate of speed at which oils of different density, in such a mixture of oils as is found in an ordinary crude petroleum, will percolate through, with the result that the first oil which makes its appearance is not only very much lighter in color, but markedly lower in specific gravity. In fact, by this process separations can be made which are quite comparable with the results of fractional distillation. There is no question but that a method is here suggested for the scientific investigation of petroleum which chemists will not be slow to utilize, and, while it is slower and not so sharp in the fractions yielded, it is perfectly evident that the oil undergoes little change due to the process of separation itself, as is almost always found to be the case in fractional distillation.

Stated Meeting, held Wednesday, December 13, 1899.

THE TILLY FOSTER MINE.

By Edward K. Landis.

This celebrated mine is situated in Putnam County, N. Y., about 52 miles north of New York City and 2 miles west of Brewster, where the Harlem and New York and New England Railroads cross each other. Brewster is also the northern terminus of the New York City & Northern R. R., since absorbed by the Harlem. This latter railroad runs through the mine property, so that the shipping facilities are exceptionally good.

HISTORY.

In 1697, William III granted Adolph Philipse a tract of land, now Putnam County, N. Y. At his death it came to his nephew, Frederick, and in 1754 Frederick's three surviv-

ing children divided the surface equally between them, but reserved the mineral rights in common. From this it would seem that the existence of valuable deposits of iron ore in Putnam County was known at this early period, but it is only since 1879 that this county has become a prominent iron producer. Desultory mining had been carried on before that time at the Sump, Croft and Tilly Foster mines, but the output was limited.

Geologically the occurrence of the ore is similar to that of the New Jersey and Lake Champlain magnetites, the country rock and physical geography being identical. The strike is N. 40°, E. and dip 66°; 66° S., 50° E.

The deposit is undoubtedly a bed. At the edges of the bed the foot and hanging walls meet, but do not coalesce, the plane of contact being distinctly marked. The two walls are separated by 3 to 6 feet of clay or gouge, which sometimes diminishes to a few inches. At the southwest end of the 300-foot level this gouge or parting was followed for a distance of 120 feet in hopes of finding another body of ore, but in vain. In the southwest end the ore is coarse-granular and coarsely crystalline, while in the northeast end it is fine-grained and finely crystalline.

In the upheavals and dislocations which were predominant features of this geological period, the strata of gneiss containing this bed of magnetite were changed from a horizontal to a vertical position, and even overturned beyond the vertical, having moved through 114°, and now dip 66° southeast. A series of vertical sections of the deposit shows the marked convexity of the hanging wall and concavity of the foot wall, from which it may be inferred that what is now the hanging wall was, before the upheaval, the bottom of the deposit.

METHOD OF MINING.

A main incline was sunk on dip of foot wall and stations cut every 100 feet, then a wide drift was run along the foot wall to the ends of the ore body. From this drift, rooms 24 feet wide with intervening 20-foot pillars of ore were turned towards the hanging wall. Each room was raised to within

15 feet to 20 feet of the one above. Enough ore was left for the miners to reach the solid stope above and only the surplus withdrawn from day to day. When the room had been stoped out all loose ore was removed and the room abandoned. All material broken was hoisted to the surface, dumped into cars and sorted. Waste usually exceeded 25 per cent. It was estimated that this method left over half the ore in pillars and floors, and in September, 1884, it was calculated that over 1,000,000 tons of ore was thus developed and in sight. At that time masonry pillars were built extending clear across the vein on the 300-foot level at three different points, about 40 feet apart, and carried up nearly 100 feet. These pillars were about 20 feet wide and were intended to take the thrust of the overlying mass, and allow the ore pillars to be robbed from between them, but the roof was not solid enough to permit this and finally the entire roof was removed and the mine worked as an open cut. This was the only method of winning the remainder of the ore, as under previous methods it was impossible to continue the operation of the mine, owing to the many accidents from falls of roof, etc. One "cave" rendered the mine unprofitable for two years.

The amount of ore mined cannot be ascertained, but through the courtesy of Mr. S. P. Tomkins, superintendent, the following figures are given:

	Tons.	
Ore mined from 1879 to 1888	335,059,	Old method.
Ore mined from 1888 to 1897	499,242,	New "
Ore shipped in 1899 (in stock)	59,679,	" "
	893,980	

The concentrating mill has shipped to date 57,977 tons of concentrated ore running 50 per cent. metallic iron and made from lean ore averaging about 28–30 per cent. metallic iron.

The total shipments of ore and concentrates from 1879 to 1899 were 951,957 tons, of which amount 616,898 tons were shipped after the adoption of the open-cut method, and could not have been won otherwise. The superintendent,

Mr. Tomkins, informs me that the ore is now stripped to a point about 430 feet from the surface, and the ore in sight and recoverable is estimated at 250,000 to 300,000 tons.

The concentrating mill has a capacity for crushing 400 tons per day of ten hours, and the two Ball steam stamps will stamp 180 tons in the same time. As $5\frac{1}{2}$ tons of lean ore are required to yield 1 ton of concentrates, the mill could turn out from 60 to 70 tons of concentrates per day.

METHOD OF MEASUREMENT.

Devised by C. C. Mattes, C.E.

The mine was divided into 10-foot squares and lines marked by stakes set well back from edge of pit. A wire rope about $\frac{1}{4}$ inch to $\frac{3}{8}$ inch stretched over a longitudinal line and trolley carrying steel tape and plumb-bob traversed along it. Level set up in north end, and H.I. determined from some convenient bench. Plumb-bob dropped to bottom and tape read, then tape wound up until plumb-bob was on crosshair of level, and tape read again. The results of these measurements were plotted on cross-section paper, and the volume excavated between the monthly measurements was calculated, the areas on the cross-sections being measured by a planimeter. This method permitted the accurate measurement of inaccessible places, and by its use a complete survey of the mine could be made in three days' time, only requiring the services of two civil engineers (one for the iron company and the other for the contractor), one levelman, and two laborers. The contractor was paid for both rock and ore on a scale varying according to the level of the material, and when a considerable depth had been reached, if a piece slid down the hanging wall from some point that could not be reached from above or below, the monthly measurement would show the original level of the material, and the contractor was paid accordingly.

On the ANNEALING of WHITE CAST IRON.

By Charles James,
Member of the Institute.

The paper on the annealing of white cast iron, which I have to present to you this evening, is not based upon laboratory experiments, but is an abstract of results obtained from daily business practice, extending over a considerable period of time. But, though these investigations were made for the guidance of commercial operations, they seemed to be of sufficient metallurgical interest to justify their presentation to you this evening.

The irons used in these operations were all of Bessemer quality, smelted with coke, no charcoal or other special iron being used. The melting furnace charges consisted of a mixture of gray and white irons, of which the following is an average analysis:

	C.C.	G.C.	Si.	Mn.	S.	P.
White iron . . .	3·50	·50	·50	·20	·08	·08
Gray iron . . .	·50	3·50	1·30	·30	·02	·03

The charges varying from 15 per cent. to 25 per cent. white iron, from 50 per cent. to 60 per cent. gray iron, and from 20 to 30 per cent. scrap iron from previous meltings. The variations being made in accordance with the variations in the components of the pig iron and the description of casting required.

The composition of the charges was regulated by the silicon content, which was made to vary from 1·20 to ·90 of 1 per cent.

The higher percentages of silicon being employed when very hot and very fluid metal was required.

The average chemical composition of these mixtures being:

	Per Cent.
Carbon	3·40 to 3·80
Silicon	·90 to 1·20
Manganese	·35 to ·20
Sulphur	·05 to ·04
Phosphorus	·04 to ·03

The iron was sometimes smelted in a cupola, but generally in an air furnace. The air-furnace charges were from 3 to 5 tons, and the furnace pre-heated to nearly a melting temperature before introducing the charge. The time occupied in melting was usually from three and one-quarter to three and three-quarters hours. As soon as the charge had completely melted, the bath was well rabbled, to obtain as complete a mixture as possible. Test pieces 8 inches long and $1\frac{1}{4}$ inches in diameter were then taken, and as soon as the iron had solidified the test pieces were rapidly cooled and broken. They usually showed a gray or highly mottled fracture, and the subsequent operations were conducted accordingly. The fining and final heating of the metal generally occupied from thirty to forty-five minutes, and was continued until a similar test piece was obtained free from all traces of gray iron. The casting made from such iron, however, frequently contains some graphite, due possibly to the different condition of cooling; but this graphite rarely exceeded one-half of 1 per cent., as the following analysis, which is an average from a large number of such castings, will show:

C.C. . 3·02 G.C. . ·47 Si . ·78 Mn . ·120 S . ·05 P . ·04

The annealing-furnace charges varied from 2 to 3 tons, the castings being placed either in the open furnace and the flame and furnace gases allowed to pass uninterruptedly over and between them, or packed in covered boxes of cast or wrought iron. No difference in the results, except as to scale, was to be observed or detected by either chemical analysis or physical tests, provided the heat treatment was conducted so as to compensate for the changed conditions. Castings packed in boxes, being practically solids of the same dimensions as the boxes, require a longer time to attain the same heat condition throughout their mass than do individual castings treated in the open furnace. But, as castings packed in boxes retain their heat for a greater length of time, and as the annealing effect continues for some time after the mass begins to cool, the total time required for either operation is nearly the same.

The weight of the various castings treated ranged from half (½) an ounce to 2,000 pounds and over. The time required to effect the carbon change—to be hereafter described—varied from three and one-half to ten hours, from the time the castings had attained their full temperature. The temperature at which the carbon change takes place in castings of this description lies between the melting points of silver and copper, and may, therefore, be approximately taken as 1,850° F.

The change in the condition of the carbon, in irons of different composition, occurs at different temperatures. The range of temperature, however, at which the changes take place in different irons is not very great, and is always closely related to and governed by the temperature of their solidification, and this temperature in turn is largely governed by the relative amounts of carbon, silicon, manganese and sulphur contained in the iron.

For irons of similar composition, the length of time required to complete the annealing effect in any casting depends upon the section area of that casting.

Thus, of two castings of similar chemical composition before annealing, but of different sectional areas, the one weighing 53 and the other 1,890 pounds, the smaller casting, after three and one-half hours' annealing, had the following chemical composition :

C.C. . . . ·61 G.C. . . . 2·83

and the larger casting, after seven and one-half hours' annealing, gave :

C.C. . . . 1·65 G.C. . . . 1·85

This casting had to be returned to the furnace and subjected to a further annealing of three and one-half hours' duration, after which it approximated closely in chemical composition to the smaller casting.

The change of carbon in castings subjected to the annealing process, though gradual, is co-extensive throughout any given cross-section of the casting ; no hard center or core of white iron, surrounded by softer metal, having ever been observed in any of the castings examined. No matter at

what period the annealing process may have been arrested, the total surface of any fracture always showed a similarity in the condition of the metal, provided the composition of the metal was homogeneous, and the heat treatment had been applied equally to all parts of the casting.

We will now consider the nature of the change or changes that occur in the casting during annealing, and to enable us to do this we will take the analysis of an average casting produced by this process, both before and after annealing:

Before annealing .	C.C., 2·60	G.C., ·72	Si, ·71	Mn, ·110	S, ·045	P, ·039
After " .	" ·82	" 2·75	" ·73	" ·108	" ·04	" ·039

From these analyses it will at once be seen that the only change effected is one of condition in the carbon, a large proportion of which has passed from the combined into the graphite state. I wish, however, to say that, though for convenience the term graphite is employed in stating the analyses of these castings after annealing, the condition of the carbon—as I shall presently show—differs very materially from graphite; either as found free in nature or as solidified out from gray iron during cooling.

It has already been shown that the relative quantity of combined and graphitic carbon found in any specimen of iron after annealing depends upon the heat treatment it has received in relation to its chemical composition and sectional area. And it now remains to inquire what effect the other components of the iron exert upon the carbon change. This question has been directly investigated only so far as silicon, manganese and phosphorus are concerned. And of these phosphorus can at once be dismissed with the remark that, in all cases, it was found to be inoperative, at least in the small amount in which it was present in these castings.

With respect to sulphur, the investigations are not yet completed, but are still in progress, and, at a future date, I may be able to lay before the Section some data respecting its influence.

Both silicon and manganese exert great influence upon the carbon during the annealing process, the presence of

silicon being a necessary condition to the carbon change. In low silicon irons it is very difficult, and, in some cases, impossible, to effect the carbon change no matter how long the iron is exposed to the heat treatment. This fact is strikingly illustrated in the following example:

A casting about $\frac{5}{16}$ inch in thickness and weighing less than one pound, and of the following composition:

C.C. . . . 2·08 G.C. . . . none Si . . . ·42 Mn . . ·05

was subjected to the usual treatment, but after being annealed for three and one-half hours the casting was still hard, and had a white iron fracture, and analyzed

C.C. . . . 1·97 G.C. . . . none

After a second annealing of three and one-half hours the appearance of the casting was still unaltered, and the analyses gave:

C.C. . . . 1·98 G.C. . . . trace

Subjected to a third annealing of three and one-half hours the casting was still hard and had a white iron fracture, and analyzed

C.C. . . . 1·90 G.C. . . . ·14

Thus, after being exposed for ten and one-half hours to the full annealing temperature, as well as passing three times through the much longer period of heating and cooling, only ·14 of 1 per cent. of the combined carbon had been changed to the graphite state.

In the example just given, both carbon and manganese, as well as the silicon, are comparatively of low percentage.

In the following instance, however, the carbon and manganese are both of fairly high percentage, but the casting, after repeated annealings, analyzed

C.C. . . 1·76 G.C. . . . 1·08 Si . . . ·31 Mn . . . ·126

and the iron remained hard and white, and could not be machined.

Indeed, the relative amount of carbon that can be changed from the combined to the graphite state during annealing

seems to be directly proportionate to the amount of silicon present, as indicated by the following example, in which all three samples were taken from the same cast, annealed in the same furnace at the same time and under identical conditions:

No. 1—C.C. . . 1·49	G.C. . . 1·40	Si . . ·56	Mn . . ·126
No. 2—C.C. . . 1·57	G.C. . . 1·33	Si . . ·45	Mn . . ·130
No. 3—C.C. . . 1·87	G.C. . . 1·03	Si . . ·31	Mn . . ·126

In this instance the total carbon and the manganese are practically the same in all three examples, and of comparatively high percentage, the silicon being the only varient, except the condition of the carbon, which is less and less changed as the silicon in the iron decreases.

That low carbon, or at least comparatively low carbon, does not prevent the change in the carbon condition taking place seems well illustrated in the following example of a comparatively low carbon iron subjected to three and one-half hours' annealing:

Before annealing	. C.C. . 1·94	G.C. . none	Si . ·64	Mn . ·09
After "	. C.C. . none	G.C. . 2·00	Si . ·62	Mn ·110

In this instance the percentage of silicon is slightly under the normal amount usually present in this class of castings, while the manganese is well up to its average in such castings.

The influence of the manganese on the carbon change is not nearly so marked as that of silicon, and its action is further obscured by the high silicon which always accompanies high manganese, for, as the percentage of manganese rises in the casting, the percentage of silicon rises also. Comparatively high manganese, however, assists the carbon change and shortens the time necessary for its completion. This is illustrated in the following analyses of a high manganese casting after being annealed for three hours only:

Before annealing	. C.C. . 3·68	G.C. . none	Si . ·93	Mn . ·30
After "	. C.C. . none	G.C. . 3·62	Si . ·95	Mn . ·31

In this instance the casting showed signs of overannealing, and the process had evidently been carried on much longer than was necessary.

The action of silicon and of manganese upon the carbon change is apparently of an essentially different character, that of silicon being direct upon the carbon, compelling it to change its condition, while the influence of the manganese is only indirectly upon the carbon through the silicon by protecting the latter from oxidation during the melting of the iron, thus causing the percentage of the silicon in the casting to be higher than it would be if the manganese had itself been more completely oxidized from the bath. This also accounts for the fact that comparatively high silicon and comparatively high manganese and the reverse are always coincident.

In every case, however, irons low in silicon and manganese are practically worthless after annealing. Such irons may be softened by the process, so as to machine easily, but are always deficient in tenacity. They generally have a white fracture, in appearance like that of a 30 per cent. carbon Bessemer steel bar. The analyses, after annealing, of two such irons are given for comparison:

No. 1—C.C. . . 2·65	G.C. . . none	Si . . ·46	Mn . . trace
No. 2—C.C. . . 1·97	G.C. . . none	Si . . ·42	Mn . . none

The analysis shows that there was no change of the carbon conditions during annealing. The samples machined easily, but broke to pieces under the pressure of the lathe tool.

That this change of carbon, from the combined to the graphite condition, can be produced by this method of annealing in other combinations of iron and carbon, as well as in white iron castings, is proved by the following experiment carried out upon a hammered bar of crucible tool steel, which analyzed before annealing:

C.C. . . ·97	G.C. . . none	Si . . ·32	Mn . . ·31

After four hours of annealing, the sample exhibited only the appearance of well-annealed tool steel, except that a skin of bright iron, similar to that seen around some malleable iron casting, had appeared. After a second annealing for four hours, the bright skin had deepened into the bar, and the remaining portion of the cross-section had a leady

appearance. After a third annealing of four hours, the bright skin had increased still more in depth, and the remaining portion of the cross-section had become black with graphite carbon, some bright spots, however, still being visible. The bar then analyzed:

C.C. . . ·47	G.C. . . ·42	Si . . ·38	Mn . . ·30

showing that nearly 50 per cent. of the carbon had changed its condition, the loss of carbon shown by this analysis being due to the decarbonizing of the surface of the bar.

Lastly we have to consider the nature of the carbon found in the castings after annealing. The carbon thus formed is evidently identical with what Ledebur has called "tempering graphite carbon," and is an allotropic form of graphite, and not merely amorphous carbon, since I find, by experiment, that it differs from both these varieties of carbon in its specific gravity, specific heat and calorific power, which after careful examination I find to be as follows:

Specific gravity	1·9 as compared to water.
Specific heat	·2237
Calorific power	7893 heat units.

That this allotropic form of graphite should have been mistaken for a graphite similar to that of gray cast iron, though it has none of the bright scaly luster of the latter, is not surprising, since it can be both separated from the iron, and chemically determined in the same manner as the graphite, from gray iron, though its combustion is much more difficult.

The chemical and physical condition attending the formation of this allotropic graphite during the annealing process, and its probable molecular form, as well as the position it occupies in the structure of the casting, which differs so remarkably from the position occupied by graphite in gray iron, have already been described in a paper read by me before this Section in 1897. And I need not now refer to this part of the subject, further than to say that the change, as at that time pointed out, affords a striking example of the solution of one solid in another, at temperatures below the melting point of either.

Contrary to Ledebur's statement, that "tempering graphite carbon" is unaffected by the hardening process, I find that iron containing this allotropic graphite hardens and tempers excellently well, and that when not fully developed by over-long annealing, the whole of this carbon will pass into the hardening state and leave the iron without a trace of free carbon.

I also find that, by prolonged heating, this allotropic form of graphite becomes changed to graphite identical with that found in gray iron, and that it then occupies a similar position in the iron structure, and greatly injures its physical qualities, so that overannealing should at all times be carefully avoided.

Photographic and Microscopic Section.

Stated Meeting, held Thursday, May 3, 1900.

NOTES ON GOLD-SODIUM CHLORIDE.

By Lyman F. Kebler.

If any one will take the trouble to obtain quotations from the various manufacturers, or consult their price lists, it will become apparent at once that there must be either a considerable margin of profit for some, or that the gold-sodium chloride varies much in composition. The difference in prices, or information on the labels are such, however, that the various makes come into direct competition with one another. For example, 1 ounce of gold-sodium chloride, U.S.P., in $\frac{1}{8}$-ounce vials, is quoted by several makers (wholesale price list) at $5.90, $6.10, $7.50, $9.60 and $14.50, respectively. Again, some makes, without any specifications as to quality, are generally quoted a few cents below those containing information as to quality.

It must be remembered that the 1890 Pharmacopœia requires this article to contain 30 per cent. of metallic gold, and a commercial article may contain less for photographic

purposes, but the latter should be so labelled as not to be brought into direct competition with the more costly article. If a certain article is prepared for photographic purposes or for some other purpose, let it be so labelled as not to be misleading.

In order to get positive information about this article the writer secured a number of samples, and a careful examination of the same gave the following results:

ANALYTICAL DATA OF GOLD-SODIUM CHLORIDE.

Number.	Condition.	Reaction to Ammonia on Glass Rod.	Reaction to Litmus.	Weight in Grains in 15-gr. Vial.	Solution Containing 15 gr. in 100 c.c. Dist. Water.	Marks on Labels.	Actual Per Cent. of Metallic Gold Gravim.	Per Cent. of Gold Based on 15 Grains Gravim.
1	Quite moist	None	Acid	13·55	Slightly opalescent	15 grains	23·55	21·29
2	Dry	"	"	14·42	Clear	15 grains	27·22	26·13
3	Dry	"	"	14·86	Slightly opalescent	15 grains	25·00	24·68
4	Dry	"	"	17·53	Clear	15 grains U.S.P.	28·31	32·91
5	Slightly moist	"	"	14·45	Clear	15 grains U.S.P.	30·30	29·02

The amount of material contained in each vial was estimated by removing the stopple, determining the gross weight, then carefully removing the chemical by means of water, drying the vial and obtaining its weight. From these weights the amounts of gold-sodium chloride in each vial can readily be calculated, and if there should be an error in any direction, it is quite likely to be in favor of the chemical.

The metallic gold was estimated as follows: Transfer the contents of a vial into a 250 cubic centimeter evaporating dish, by means of 100 cubic centimeters of a 1 per cent. solution of pure sulphuric acid. In this mixture dissolve 2 grains of pure oxalic acid, then place the whole on a steam-bath for two hours, or until all the gold is reduced to the metallic state. Decant the clear liquid as closely as possible, wash the gold with distilled water, dry, ignite and weigh. This method works well, but the volumetric process for this purpose appeared to be valueless.

From a careful perusal of the data contained in the foregoing table, it can readily be seen that all the samples were of good quality, but there is a wide variation in the percentage content of gold.

In order to fully comprehend the actual difference in money value existing between the various samples, it is only necessary to compare the figures below:

Number.	100 Ounces Gold-Sodium Chloride Contained Pure Gold.	Cost at $21 Per Ounce.
1	21·29	$447 09
2	26·13	548 73
3	24·68	518 28
4	32·91	691 11
5	29·02	609 42

The greatest difference, based on the cost of the gold only, amounts to $244.02, or by eliminating the highest, which appears to be somewhat abnormal, the difference becomes $162.33. In other words, the purchaser of 100 ounces of the article containing the smallest per cent. of gold is paying $162.33 for something he is not getting. In this case, as in many others, the cheapest is the most costly.

NOTES AND COMMENTS.

A RIVAL TO CELLULOID.

The British *Journal of Photography* calls attention to the fact that nitrated cellulose has long held the field as the basis of a flexible glass, as celluloid has been called; but there seems a probability that before long Messrs. Cross and Bevan's invention, aceto-cellulose, may be found a formidable rival, for it possesses many advantages over the pyroxylin, which, in combination with camphor, is the main constituent of celluloid. * * * Perhaps the most conspicuous quality of the acetate compared with the nitrate is its non-inflammability—it burns very imperfectly. It differs further from the latter in that it is insoluble in methylic and ethylic alcohols, acetates of amyl and ethyl, acetone and ether, but is soluble in benzoate of ethyl, chloroform, epichlorhydrine, acetic anhydride, glacial acetic acid and nitro-benzine, the solution in the latter becoming a solid, completely transparent jelly. The solution in the other named liquids can be diluted with acetone without precipitation taking place. The

aceto-cellulose resists most reagents in a remarkable manner. Dilute acids and alkaline dyes destroy nitrocellulose; but, with the exception of dilute nitric acid, do not act upon the new substance, in some cases even when boiling. It is probable, too, that, used as a basis for films, it will be possible to dry them quickly by the aid of alcohol in the usual manner, a process quite out of question with celluloid, as any one knows to his sorrow who has tried it. W.

BOOK NOTICES.

Theatres: Their safety from fire and panic, their comfort and healthfulness. By Wm. Paul Gerhard, C.E. (8vo, pp. 110.) Boston: Baker & Gould Company. 1900.

This volume is a collection in book form, with additions, of various articles contributed by the author to the British Fire-Prevention Committee and the *Popular Science Monthly.*

This subject is treated under two heads: (1) Safety from Fire and Panic; (2) Comfort and Sanitation.

The author has given both phases of his theme careful and intelligent consideration, and the book should prove a great help to architects and proprietors of this class of buildings. W.

Practical Methods for Determining Molecular Weights. By Henry Biltz, Privat-Docent at the University in Greifswald. Translated (with the author's sanction) by Harry C. Jones, Associate in Physical Chemistry in Johns Hopkins University, and Stephen H. King, M.D., Harvard University. Easton, Pa.: The Chemical Publishing Company. 1899. 8vo, pp. vi–235. (Price, $2.00.)

In this work, Professor Biltz has collected and arranged in proper sequence all the methods that have been devised for the determination of molecular weights, with full descriptions and illustrations of the various forms of apparatus employed, and the manner of carrying out the experiments.

The references to original sources are so freely given throughout the book as to make it not only a satisfactory guide to the investigator in actual laboratory practice, but also a valuable reference book to the literature of molecular weight determinations.

The work of the translators has been done very satisfactorily. W.

Electric Power Transmission. By Louis Bell, Ph.D. (Second edition, revised and enlarged.) New York: Electrical World and Engineer, Inc. 1899.

Electrical engineers are quite familiar with this excellent treatise, which appeared originally in 1897. The present edition has been carefully revised and enlarged by the addition of a fresh chapter, in which are set forth the recent important advances in the art of power transmission at very high voltage and to long distances, and the recent additions to our knowledge of the theory of high-voltage phenomena. W.

Hand-book of Testing Materials. For the constructor. Part I. Methods, machines and auxiliary apparatus. (In two volumes. Vol. I, text; Vol. II, illustrations.) By Prof. Adolph Martens, Director of the Royal Testing Laboratories at Berlin and Charlottenburg. Authorized translation and additions. By Gus. C. Henning, M.E., Member of the Intern. Association for Testing Materials, etc. 8vo. Cloth. 2 vols. Vol. I, pp. li-622. Vol. II, 1,030 figures. New York: John Wiley & Sons. London: Chapman & Hall, Ltd. 1899. (Price, $7.50.)

The methods of testing materials of construction have probably come in for a greater share of attention during the past decade than any other branch of applied science. With the great advances in the metallurgical arts more especially, and the prodigious increase in consumption in the arts of peace and war, have come more onerous requirements as to the quality of material and more rigid systems of inspection. The world-wide interchange of products of this class and the active competition among manufacturers have made the need of uniformity of methods of testing felt most keenly, and the formation of an active international association for accomplishing this object is evidence that its importance is fully appreciated.

The thorough work of Professor Martens, one of the masters of this branch of applied science, is a most valuable and timely contribution to the subject, and will undoubtedly contribute substantially to the work of establishing uniformity in methods of testing and in giving the engineer a more precise and scientific knowledge of the properties of materials used in the constructive arts.

Part I of Professor Martens' work comprises the consideration of the general properties of materials of construction, testing materials, testing machines and measuring instruments. The text and plates are in separate volumes, and the references to original sources of data are elaborate and complete.

The translator is a well-known engineering expert, fully qualified by training and professional experience to undertake the responsibility of Englishing this important work, and he has done the work most creditably. W.

The Past and Present Conditions of Public Hygiene and State Medicine in the United States. By Samuel W. Abbott, Secretary of the State Board of Health of Massachusetts. (8vo, 103 pp.)

This publication constitutes the nineteenth of a series of monographs on American social economics, issued under the editorial supervision of Prof. Herbert B. Adams (Johns Hopkins University) and Richard Waterman, Jr., in the interest of the Department of Social Economy, for the U. S. Commission to the Paris Exposition of 1900, and is a contribution to this branch of the government exhibit by the commonwealth of Massachusetts.

It is a concise and thorough exposition of the progress which has been attained in the United States in matters pertaining to the public health. W.

The Railway and Engineering Review, of Chicago, has exhibited commendable enterprise in issuing in sumptuous form a "Portrait Souvenir Edition" in honor of the Master Car Builders' and the American Railway Master Mechanics' Associations, which met in convention at Saratoga, N. Y.,

June 18th–23d. The impression is embellished with nearly 400 portraits of the officers and members of the two associations, executed in the best style of the engravers' art, and will prove an interesting souvenir of the occasion. W.

Craft's Tables of Plate and Rivet Values. Thos. H. Craft, 16 Kelton Street, Cleveland, O. (Price, $1.)

These tables of plate and rivet values have been carefully worked out by the compiler for the use of boiler designers, boiler makers, inspectors and engineers, to assist in designing and calculating the efficiency of boiler joints. W.

Architects' Hand-Book on Cements. By Addison H. Clarke. Baltimore: Wm. Wirt Clarke & Son. 1899.

This handy little volume, ninety-six pages. pocket-book size, contains, in condensed form, a considerable collection of facts and data covering the mixing and using of cements adapted specially to meet the wants of the architect and builder. W.

Encyclopédie Scientifique des Aide-Mémoire. Paris: Librairie Gauthier-Villars. Small 8vo, in paper, 2.50 francs; bound, 3 francs.

The following additions to this useful series of technical hand-books have appeared since our last notice:

La Garance et l'Indigo. Par G. F. Jaubert, Directeur de la Revue générale de Chimie pure et appliquée, Docteur ès Sciences, ancien Préparateur de Chimie à l'École Polytechnique.

Produits Aromatiques Artificiels et Naturels. Par G. F. Jaubert.

Les Matières Odorantes Artificielles. Par G. F. Jaubert.

Les Parfums Comestibles. Par G. F. Jaubert.

Recherches des Eaux Potables et Industrielles. Par Henri Boursault, Chimiste à la C[ie] du Chemin de fer du Nord.

Each of these publications is complete in itself, and the series, as a whole, forms an admirable compendium of the applications of science to the arts and industries. W.

Traction Electrique. Par Eric Gerard, Directeur a l'Institut Electrotechnique Montefiore, etc. Paris: Gauthier-Villars. 1900. (8vo, pp. 136, with illustrations.)

This publication is substantially a reproduction of the course of lectures conducted by the author in the above-named institution, and much of the material contained therein has appeared in the author's "Leçons sur l'Électricité," previously noticed in the *Journal.*

The subject is treated under five heads, as follows: General Considerations on Electric Tramways; The Various Systems of Electric Traction; Making Plans and Specifications for an Electric Traction Project; Electric Railways; Cost of Electric Traction.

Many of the considerations of the author are based upon data gleaned from foreign methods of practice, and the work accordingly should be specially interesting to American engineers. W.

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THE FRANKLIN INSTITUTE.

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MISTAKES IN THE RATING OF INCANDESCENT LAMPS.

BY ARTHUR J. ROWLAND,
Member of the Institute.

A 16 candle-power lamp is such a common article of commerce and in such general use that we all recognize it when we see it, or think we do, either by the size of its bulb or the length of the filament, or both. Very few people go beyond such mechanical identification except for the extra assurance they gain by a look at the manufacturer's label. Some, indeed, presume to tell that a lamp is of a given candle-power by looking at the brightness of its filament or by considering the general lighting of a room; but it need scarcely be said that an estimate formed by such a method is utterly worthless, since one is too much influenced by contrasts in brightness, or deceived by the temperature at

which a given filament is burned, to really tell anything at all about the candle-power.

The importance of exact knowledge of the candle-power of incandescent lamps is at last being recognized among lamp users generally. One of the signs of this in the present times is the great number of photometers recently set up and used outside of laboratories. Certain standard measurements are made with these, which are good so far as they go, but commonly many important things are quite passed by unnoticed. Not only should the user of incandescent lamps want to know that the lamps he buys really have the candle-power marked on them, and that they maintain their candle-power properly as they grow old in service, but he ought to know and fully understand a number of other things regarding the real candle-power and watts per candle-power of the lamps he uses. Some of these seem to have quite escaped notice, and their importance is so great as to merit careful consideration.

WHAT A 16 CANDLE-POWER LAMP OUGHT TO BE.

Let us first inquire into just what a 16 candle-power lamp ought to be. That it should be one which gives a light equal to that of 16 candles in the direction in which the light is useful seems a natural and fair definition. A little careful observation of lamps as they are installed shows that at least 85 to 90 per cent. of those used are put in place with base upward, or tipped end downward, and it is the light which comes from this tipped end of the lamp which is useful. In cases where the lamp is installed in a different position, either the lamp is subordinated to some artistic feature of the electrolier, or the lamp is installed "side on" to better keep it out of the way. So it comes that the light we ought really to want to know about, the light we ought to measure, is that coming out of the end of the lamp. Or at least it is sure that, if we call the axis of the lamp a line through it from the middle of the base up to the sealed-off tip, the light of value is that coming into space below a plane perpendicular to the axis, half way along its length. We can never use more light than

this, since for satisfactory lighting the sources must be above us, and in real service we make use of much less, as will be presently shown. Should we take the average candle-power of all the light rays into space below the imaginary plane just defined, this would be called the mean hemispherical candle-power, just as the average candle-power of all the light rays given by the lamp in every direction is called the mean spherical candle-power.

THE IMPORTANCE OF THE LIGHT FROM THE TIPPED END.

The placing of lights is to-day being made much more intelligently than by the old rules of so many 16 candle-power lamps per 100 square feet of floor surface, or per 100 cubic feet of room to be lighted. Some certain amount of illumination is now striven for, and a proper distribution of light rather than of lights is sought.

In a great deal of lighting one tries intentionally to give illumination concentrated about particular points. For example, in lighting a library it is the library table which is to be brightly lighted; other parts of the room need little more than the scattered rays otherwise useless, which reach them directly from the light source or after reflection. The light rays in poor planes and the reflected light which comes from the table, the walls and objects in the room, though contributing little to the important light, serve to break up shadows and produce diffusion. Almost the same thing would be true of the lighting of a bedroom, where the light should be concentrated about the bureau or dressing table.

In quite a different sort of lighting, still the same things hold true. Take the lighting of a factory or mill for example. The light must be on the machines or work, and be very good there. That which gives the room its general lighting is waste light from the light sources. To light the whole room as brightly as the machines would be too costly to be practical. For such lighting let us consider what rays are useful and what rays waste light. If the lamp hangs directly above the thing to be lighted, and its area be not more that 5 x 5 feet, no rays of light beyond 30° from the

axis of the lamp will be useful, and the higher the lamp is hung, the less the angle in which the useful light is found.

A second sort of lighting is that in which a uniform distribution of light is required, as in concert halls, or auditoriums of various sorts, and in shops for the sale of merchandise. A fundamental principle in this class of lighting is to use many sources of small candle-power each, all so placed that the light from them is directed downward, with perhaps a little diffused side light to break up the shadows, especially in small interiors. The lighting engineer is forced to use single lamps to procure this, except in large rooms, and they are nearly always installed base upward. The light from the tipped end produces the light of value.

A third sort of lighting is for decorative purposes, but that is so very especial and foreign to considerations of candle-power at all in most instances as to merit no consideration here.

The light below the lamp—that from the tipped end—is then the important and useful light in all practical cases. This is true, too, not only from the specific cases cited, but where large electroliers with many lights are used as well; for in such cases the lamps are usually flared out, with axes at some angle approaching 45°, in which case high candle-power from the tipped end and low from the sides of the lamp would contribute to a good, even illumination of the room.

The importance of procuring high candle-power below the lamp has been recognized a long time. But what expensive and roundabout methods have been taken to procure it! It is very common to use reflectors to increase the amount of light in the direction below the lamps. While reflectors have their place in lighting, and an important one, too, for most purposes they are exceedingly poor and are used in ignorance of the effects they produce or because no better device for light redistribution can be had. No matter whether the reflector covers the lamp or not, no matter whether it is of porcelain, a glass mirror, or a polished metal surface, it inevitably cuts the light off absolutely in some

directions and so directs it in others as to produce sharp shadows and brilliant lighting contrasts. In satisfactory lighting contrasts of light and shade are always avoided, and by producing diffusion most shadows are lost. Other devices, like McCreary shades and specially shaped incandescent lamps having a reflector incorporated with the lamp, have faults precisely the same as reflectors. Holophanes, with their prismatic and accurately formed surfaces, turn the light downward and at the same time diffuse it by refraction, so that on all artificial lights the distribution of the light, and the lighting therefore, is improved by their use. A holophane gives a redistribution of light immeasurably better than a reflector always. If an incandescent lamp is installed base down, holophanes or reflectors must be used on it or the lamp be valueless in supplying really useful light.

The common use of such devices is evidence that the ordinary incandescent lamp does not give as much light below it as is required there. Is there, then, a bad light distribution from them? An examination of modern lamps will tell us.

FILAMENT TYPES AND CANDLE-POWER DISTRIBUTION.

There are five different types of filament in use to-day by various prominent lamp manufacturers, and in most cases a filament type indicates the product of a certain manufacturer who has adopted that as the one used in his standard lamps. These typical filaments are enough different from each other to show interesting individuality. I have classed them as follows:

(*a*) Straight U-shaped filament; a type rapidly passing altogether out of use.

(*b*) Single curl filament; a type much used, having a circular loop in the filament midway of its length. This type was originally designed to render filaments stiffer and less liable to bend without an anchor, and also to shorten the lamp bulb. It was found to give a better distribution of light than type *a*.

(*c*) Long curl anchored filament; a type differing from

type *b* in that the loop is long in the direction of the lamp axis and is anchored to the part of the lamp where the leading-in wires pass through the glass.

(*d*) Double filament; a type which uses two filaments like type *a*, set so the current passes through them in series, the filaments being in planes approximately parallel.

(*e*) Double coil filament; a type like *b*, except that there are two turns in the coil instead of one.

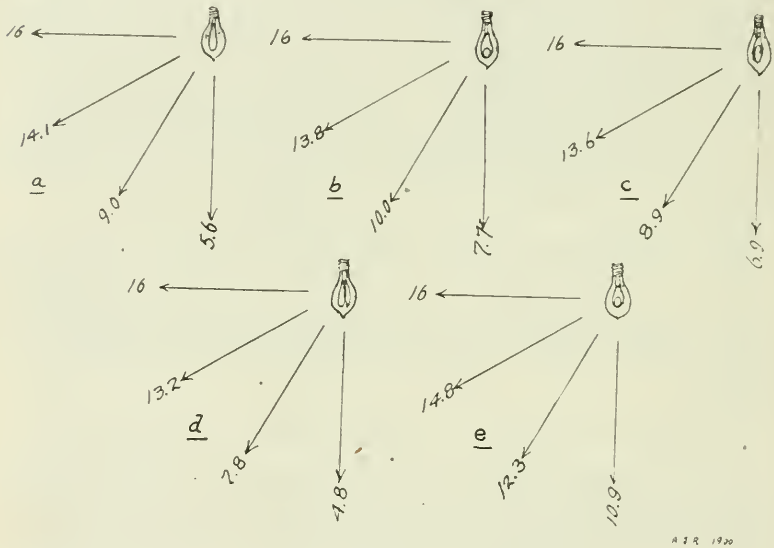


FIG. 1.

(*a*) Straight U-shaped filament.
(*b*) Single curl filament.
(*c*) Long coil anchored filament.
(*d*) Double filament.
(*e*) Double coil filament.

Showing average candle-power distribution from incandescent lamps of various types.

Besides being typical in the matter of general form, the light distribution observed from these various filaments is also typical. It is, however, considerably influenced by the exact relation of different dimensions in the filament itself used by particular firms; as, for example, the diameter of a coil or the spread of the filament shanks. Results below are therefore departed from somewhat if different makes of lamps had been used in the tests.

Fig. 1 shows average candle-power values from lamps of each of the different types. The arrows indicate the direction from which the candle-power was measured and the number gives the candle-power. These values are true averages of the types shown. In the averages struck no "freak" lamps were included. The five types are each represented by the product of some prominent lamp maker. All the lamps are rated 16 candle-power, all were in the standard bulb used by the manufacturer of a type, and, as it happened, all were 3·5-watt 110-volt lamps. A careful inspection of the figure shows one that the form of filament has a most important relation to the candle-power distribution, as of course it must, since the candle-power delivered in a given direction is determined almost wholly by the amount of filament length visible from that direction. A filament of type *a* shows only the end of the U when one looks in at the tip, and so the candle-power must be low, even if the U be broad. A double filament must show low candle-power for the same reason; and if the filament loops are narrow and the legs of the filaments straight, as they were in the lamps of the make tested, the candle-power may be even lower out from the tipped end than for a filament of type *a*. A filament with a coil in it shows much more projected length when viewed from the lamp's end, and so gives comparatively high candle-power in that direction. We see, then, that a 16 candle-power lamp is very different in the candle-power it gives in various directions and very different in a given direction with difference in type of filament. That lamp which gives most useful light is undoubtedly the best. Hence there is no question but that the 16 candle-power lamp with filament of type *e* is a far better lamp for general lighting purposes than any other. It is almost beyond belief that this has escaped notice in all the years incandescent lamps have been made and used, and yet it has been so. I first had my own attention called to the matter by the Shelby Electric Company, for whom I was making some tests of candle-power. It is their lamps which I show as type *e*. In an attempt to find whether in the past any one had attached importance to the light coming out from the

tipped end, I have been surprised to note how, over and over, this or that experimenter or lamp manufacturer has been on the verge of the discovery and then passed it by. One of the most recent cases I have noticed is that of a lamp manufacturer who advertised sign lamps with "all the light from the end," but seems never to have thought that this would be the right sort of lamp to use as his standard product.

Fig. 2 gives the relative amount of useful light from filaments of the different sorts, expressed in per cent. of the light given by the double coil filament (type *e*).

Filament.	Light in Given Direction in Per Cent.	
	Vertically Downward.	30° from Vertical.
Type *e*	100·	100·
" *d*	44·0	63·4
" *c*	63·7	72·4
" *b*	70·6	81·3
" *a*	51·4	73·2

Fig. 2.

The Shelby lamp (type *c*) for which data is given was made tipless; that is, the sealing off after exhaustion was not done as usual at the tipped end. The gain in candle-power by omitting the tip, so far as tests which I have been able to make indicate, is about 12 per cent. The loss in tipped lamps is probably due to light absorbed through the thicker glass at the tip and partly to reflection and refraction of light into useless directions which otherwise might have been saved to be useful.

What folly it turns out to be to use special devices to turn the light downward when the lamp itself can have the filament constructed so as to give a proper light distribution. A design of filament for incandescent lamps so they will give large candle-power from the tipped end is second in importance only to satisfactory efficiency and maintained candle-power with fair average life.

ILLUMINATION BY LAMPS USING FILAMENTS OF DIFFERENT TYPES.

A large amount of light streaming from the end of the lamp is only useful if it produces a proper illumination. In *Fig. 3* is plotted the illumination of a level surface 5 feet below a 16 candle-power lamp of different makes, the dis-

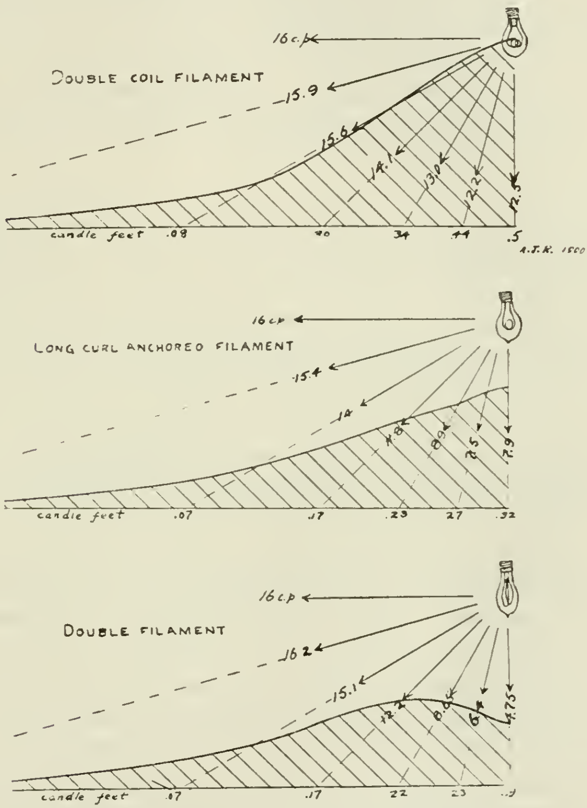


FIG. 3.—Illumination by filaments of different types.

tribution being shown one way out from the lamp only. A single representative lamp was taken of each of three important sorts and the candle-power as marked on the diagrams determined for the light given in each of the directions shown by the arrows. The illumination was then calculated in candle-feet, and this plotted vertically from

the base line. The solid curved line bounding the shaded area runs through the points so found, and all vertical distances from the base line give the amount of illumination there. Some of the values found are marked. Thus, for the long curl anchored filament ·32 of a candle-foot is procured at the surface illuminated by the ray giving 7·9 candle-power, ·27 by the ray giving 7·5 candle-power, etc. The candle-foot unit is the common one; that is, an illumination of 1 candle-foot is that of a surface everywhere 1 foot distant from a light giving 1 candle-power in every direction. A surface 2 feet distant at every point from such a light source would have an illumination of $\frac{1}{4}$ of a candle-foot.

A first look at the diagrams would seem to indicate that the double filament lamp is best, since it gives more uniform illumination than either of the others. In any case, we need not concern ourselves with the light received from rays making an angle greater than 45° with the vertical; since up to this angle a circular area 10 feet in diameter, above the center of which the lamp hangs, is being lighted. Under the lamp the light is most valuable, and there we want to get most light. The double coil filament turns out, then, to be by far the best form. If in lighting an interior the lamps were hung separately and placed about 6 feet apart, the evenness of the illumination produced would be about the same for lamps having double coil filaments, or lamps having long curl anchored filaments; but the amount of illumination procured from double coil filaments would be so much greater that they are much to be preferred. We are assuming all along that 16 candle-power lamps, as the manufacturers call them, are in use. If lamps were placed 15 feet apart, the distribution of light with double filament lamps would be very good if an even distribution is desired; but the average illumination would be low.

It is interesting to notice, in these plots of illumination, that after the 45° ray is passed the value of all types of filaments is about the same; and it should be noted that the illumination procured is very small. An illumination of $\frac{1}{10}$ of a candle-foot, for example, is that which one re-

ceives on a piece of paper held vertically more than 3 feet from an ordinary candle. Such light as passes out from a lamp in directions nearly horizontal or above the horizontal plane is useless except it is reflected back to the surfaces to be lighted or contributes to the general illumination by dispelling the gloom of the upper parts of a room and by giving a diffused character to the light. While it has such value, it is rarely that one can afford to use much light this way. If light is useful after reflection, it must travel in long paths; so that even if it reaches points where it is useful, so little illumination is produced that direct light is much the best. A very white surface will not reflect more than 85 per cent. of the light which strikes it, while dark walls and ceilings and hangings reflect almost no light at all. The item of reflected light is then one of very uncertain amount at most. Take a room in which the ceiling is only 12 feet high, in which a 16 candle-power lamp hangs 4 feet from the ceiling, and one finds that no rays from any lamp now made, passing out to reach the ceiling or wall above the horizontal plane through the lamp, will give an illumination of as much as ·05 candle-foot on a surface 5 feet below the lamp, even on the assumption that the ceiling and wall are the best possible reflectors.

INFLUENCE OF FILAMENT FORM ON CANDLE-POWER.

A number of interesting matters connected with the distribution of light from lamps having filaments of the different types are shown in *Figs. 4* to *8*, inclusive. Each figure gives the results from a test of one lamp—a lamp chosen to represent the type because it was truly representative mechanically, and by check against other lamps was found to be representative in light distribution. The rough sketch of the lamp on each figure shows very nearly the actual shape of the filament whose candle-power was measured. The left-hand sketch shows the lamp as it stood for measuring the horizontal candle-power at 0° and the right-hand figure at 90°. In all the candle-power diagrams distance out radially from the center of the diagram to the heavy curve gives the candle-power in that particular

Curve of Horizontal Distribution of Candle-Power. Curve of Vertical Distribution of Candle-Power.

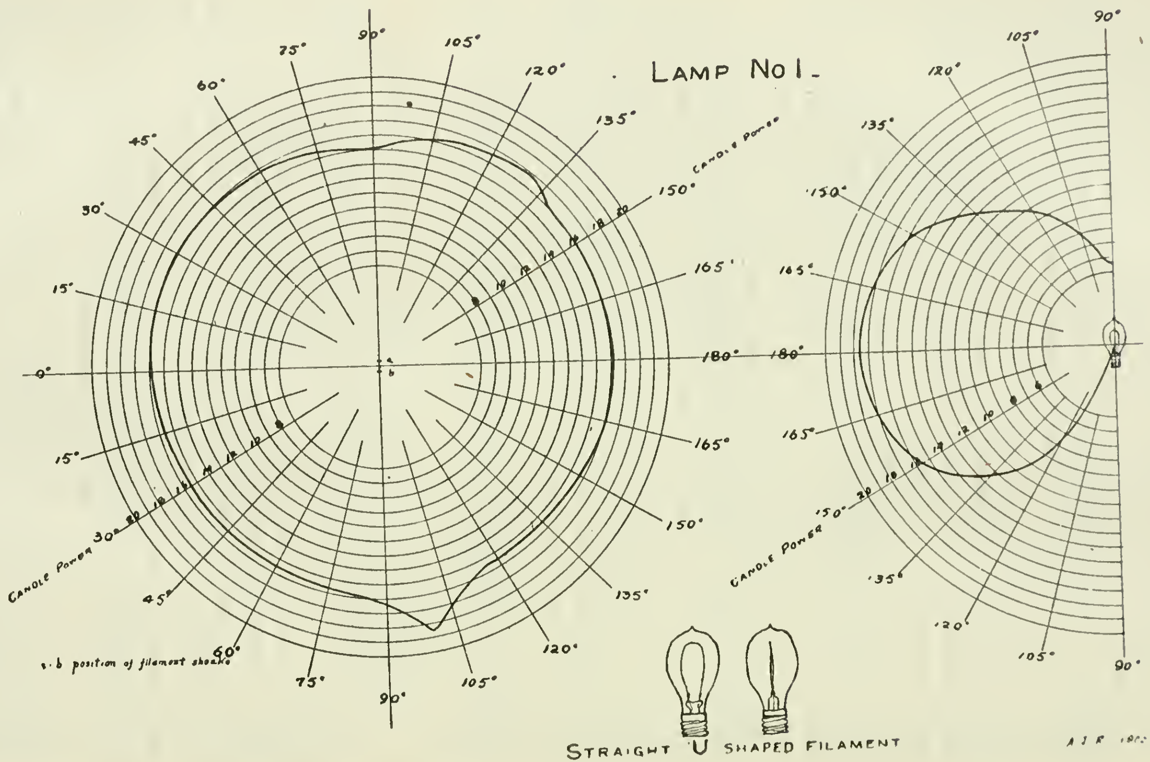


FIG. 4.

Curve of Horizontal Distribution of Candle-Power. Curve of Vertical Distribution of Candle-Power.

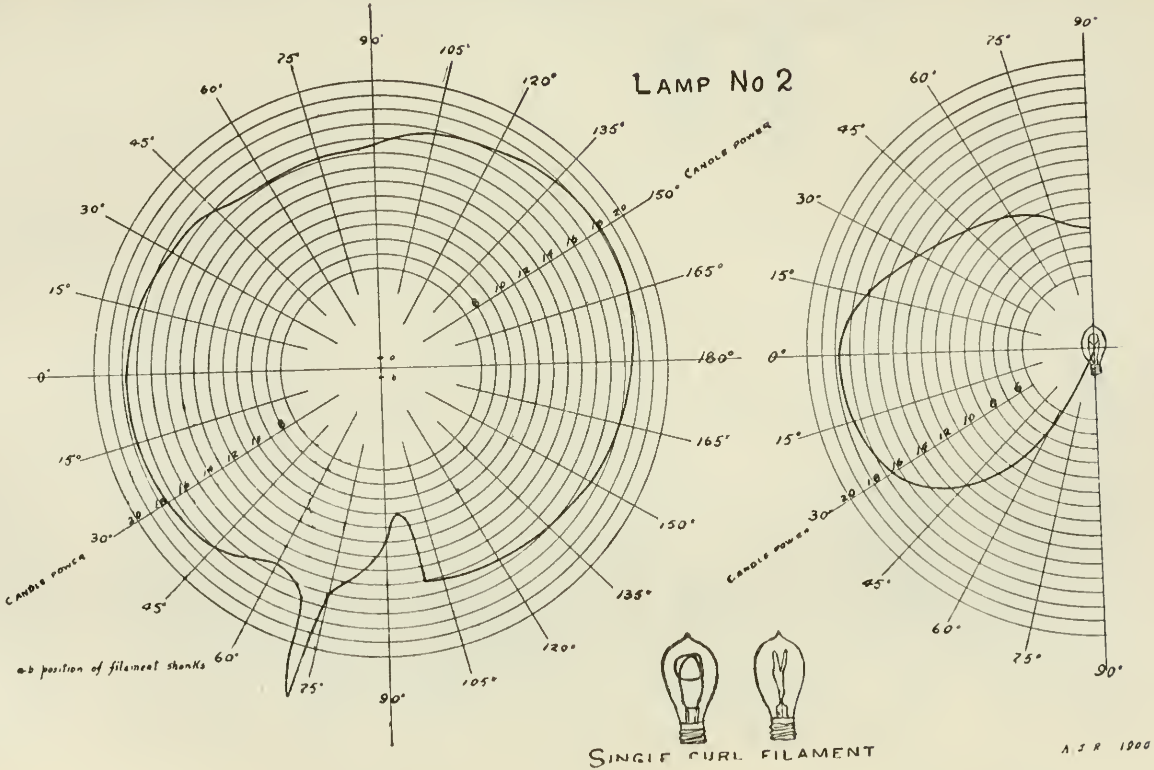


FIG. 5.

Curve of Horizontal Distribution of Candle-Power. Curve of Vertical Distribution of Candle-Power.

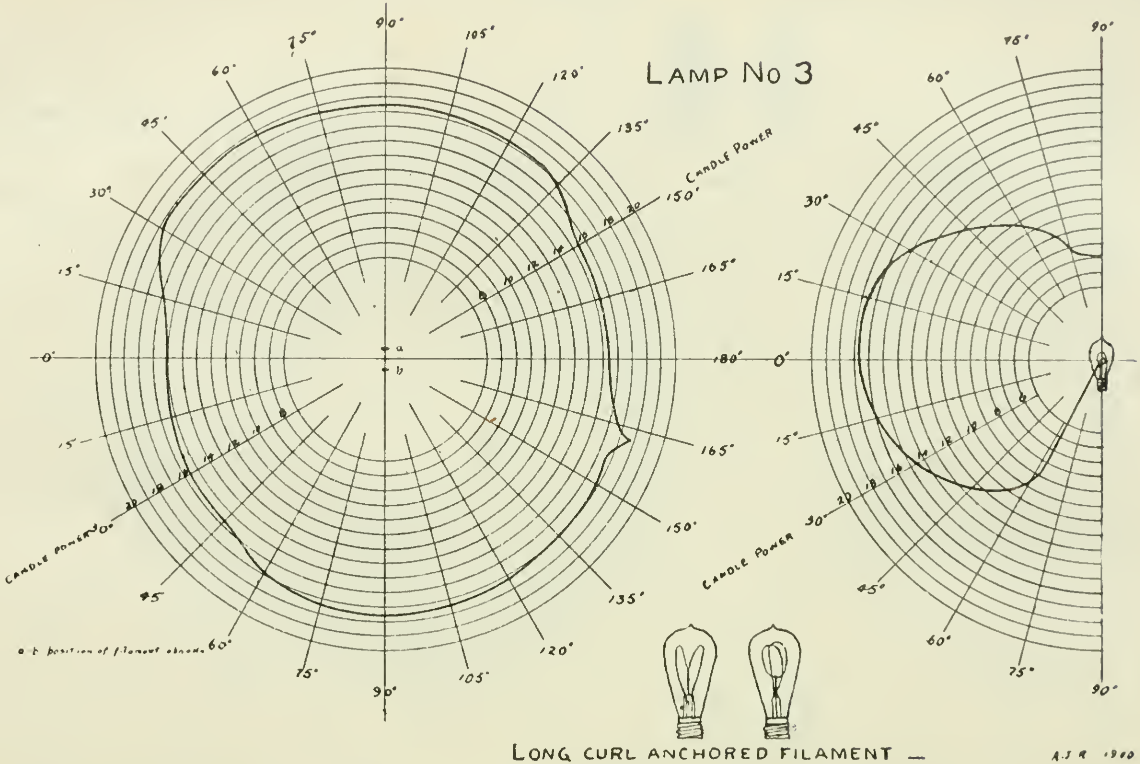


FIG. 6.

radial direction. Thus, in the curve of horizontal distribution, if the lamp stood with axis vertical and one went around the lamp taking candle-power of the light given in the direction toward him as he went on, these values of candle-power have been recorded and can be read off on the diagrams up to the heavy line. The same interpretation holds for the curves of vertical candle-power at the right of the figures.

All the lamps were kept at the voltage at which they give 16 candle-power on the basis of the manufacturer's rating. In the curves of horizontal distribution we see that lamp No. 1 with the straight U-shaped filament is quite uniform in candle-power all around. The candle-power distribution of the long curl anchored filament (lamp No. 3) and the double filament (lamp No. 4) are somewhat similar. The irregularity of the curves for lamps Nos. 2 and 5, coil filament types, is great. This is always distinctive of lamps of the sort. The striking irregularity at one point of the curve for lamp No. 2 is not abnormal. There are often two such breaks, one on each side of the lamp. The cause of this irregularity may be due to complex reflection and refraction of light due to varying thickness or curvature of the glass enclosure. It has not been investigated, I think. Since the manufacturer's rating is on the average or mean horizontal candle-power a lamp gives, the more uniform the candle-power curve of horizontal distribution, the more nearly perfect a lamp might be considered, I suppose. At least, this seems to explain the design of the most recent filament forms. But by far the most important distribution is that in a vertical plane. Here the great differences in candle-power procured from various filament forms show best. Look at the curves. Lamps Nos. 1, 3, 4 are dreadfully deficient in light from the tipped end, and the candle-power of each falls off very rapidly as the 90° angle is approached.

How especially is this true of lamp No. 4, which, just as one comes to the direction from which the light is most important (between 75° and 90° at the tipped end), drops the candle power down to less than five units. Most of the

Curve of Horizontal Distribution of Candle-Power. Curve of Vertical Distribution of Candle-Power.

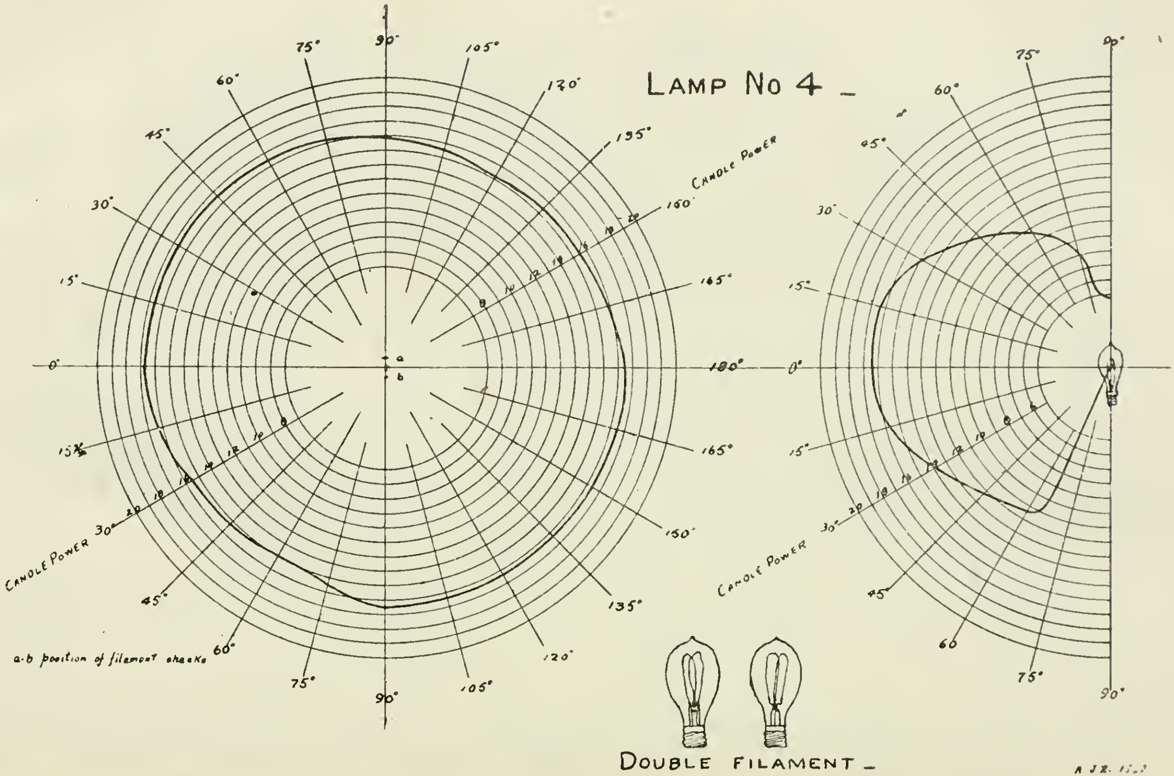


FIG. 7.

Curve of Horizontal Distribution of Candle-Power.

Curve of Vertical Distribution of Candle-Power.

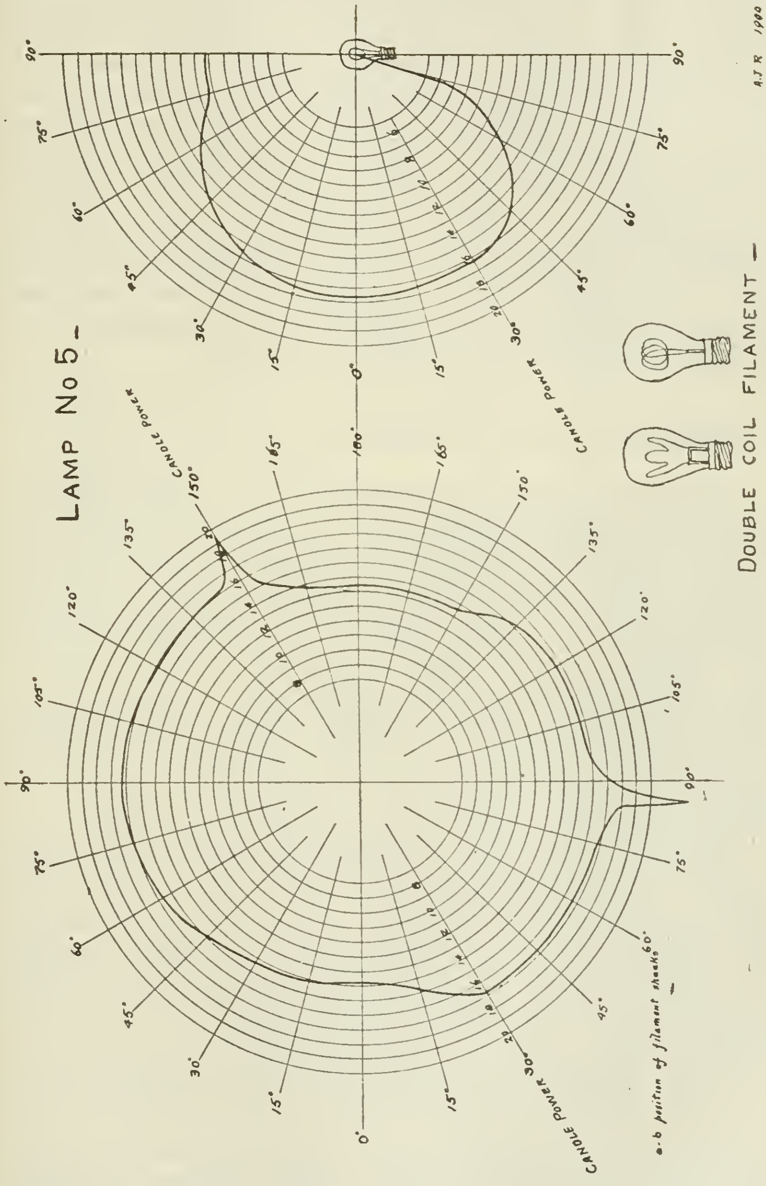


FIG. 8.

lamps, curiously enough, give most light in zones beyond the horizontal toward the base, where its usefulness is very problematical. This is true, too, of lamp No. 5, which maintains the candle-power it gives so well out toward the tipped end. It sends a good deal of light toward the base, but if we have a good light where it is useful, we must not criticise too severely the delivery of light where it has no especial value. The effect of the omission of the sealed-off tip on this lamp in helping up the candle-power at the end is well shown in the curve of vertical distribution for lamp No. 5, where from 75° to 90° the candle-power keeps up. This is due partly to the way the loops of the filament are spread, and partly to the omission of the tip.

WHAT IS A 16 CANDLE-POWER INCANDESCENT LAMP?

It does not take much consideration of these curves to satisfy one that a 16 candle-power lamp is not necessarily one which gives 16 candle-power where this much light is wanted. The candle-power of incandescent lamps is determined really in a very empirical and arbitrary fashion. Most people seem to think it is as surely known as the watts used, and is as readily measured. But really it is about as vague and elusive a value as the candle-power of an arc lamp, for which it has facetiously been said that it gives 2,000 candle-power because at any street corner it delivers 500 candle-power in each of the four directions.

The common method of measuring candle-power in use by the manufacturers of incandescent lamps is to spin them at 180 revolutions per minute on a vertical axis and measure the average horizontal candle-power by a single reading. How this comes to be accepted as satisfactory, and what the status of candle-power measurement of incandescent lamps is, will be worth a little consideration right here.

When incandescent lamps first became commercial they were put into competition with gas lights and were made so they would measure 16 candle-power when placed in a photometer, precisely as gas lights *had* to be placed—base down, and the old U-shaped filament with a plane

through the shanks of the U perpendicular to the photometer bar. Indeed, since photometers (except for purely scientific investigations) were used only for measuring the candle-power of illuminating gas, these very photometers were used for the incandescent lamps; and methods for gas photometry were adopted as far as possible into their candle-power measurement. It was soon clear that some more complete sort of measurement ought to be made, and in 1885, in connection with important tests of incandescent lamps for their economic value, probably the most elaborate tests ever made, the Franklin Institute adopted a method of measuring the mean spherical candle-power which was really an empirical or arbitrary one, but gave as a result a candle-power value quite nearly the true average of all measurements when the lamp was viewed from all possible directions.*

The measurement of the mean spherical candle-power by the Franklin Institute method requires that at least between forty and fifty measurements on the photometer be made, and the average of thirty-eight determinations is taken to get the result. About two hours' time for two operators with a well-equipped photometer laboratory is required for the measurement of one incandescent lamp, while the apparatus required, as supplied by instrument makers, is defective in that it does not enable satisfactory measurements of the light radiated in directions near the lamp base to be made. While, then, this method came near giving the real average candle-power of a lamp, it could not well be used by lamp manufacturers in rating their product, nor was it. Most of them rated their lamps by the candle-power measured when the lamp stands vertically with base downwards and the bar of the photometer points to some selected side of the lamp. Some attempts were made to use a constant number by which this reading of candle-power might be multiplied to give the mean

* The influence of candle-power measurements of gas upon similar measurements of incandescent lamps is well shown by the fact that the photometer expert of the Franklin Institute committee was Dr. Ward, the Philadelphia gas light photometric expert.

spherical candle-power for a given type of lamp, but without success in commercial usage.

In recent years, lamps have been measured by their mean horizontal candle-power and so rated. To save time, the manufacturer has lamps standing in the position already described, but has them rotating when the candle-power is measured. 180 revolutions per minute is a common speed, and the voltage marked on the label is that required to give 16 candle-power when the lamp is so rotating. The user who checks the manufacturer's product as it is delivered to him must perforce use the same method.

The National Electric Light Convention, not satisfied with the uncertainty of the methods in use, and in order to procure uniformity of standards and practice in rating lamps, appointed a committee, who made a report at the convention in June, 1897, in which they say that the mean spherical candle-power is the only proper and fair value to consider in comparing lamps. The practical measurement of this is so difficult, however, that a simpler method was recommended whereby the average luminous output of the lamp might be measured. The proposed measurement was to be taken "in the direction inclined 45° to the axis of the lamp, while the lamp is revolving upon its axis, the distance of the lamp from the photometric screen to be regarded as the distance between the center of the axis of its bulb and the screen. This will furnish a fair approximation to the mean spherical candle-power and reduce the amount of labor in measurement to the minimum." Two revolutions per second or 120 revolutions per minute was recommended as a speed of rotation.

A year later, in June, 1898, the same committee made a further report telling of tests made, confirming the committee's suggestion of measurement at 45° of inclination and making the proper speed 200 to 250 revolutions per minute. The committee was continued and made another report at the last meeting of the convention, but altogether on other phases of the subject—photometers, standards of candle-power, etc. Here the matter rests. In spite of the official adoption of the report by the convention, manufacturers

continue to rate their lamps by a measurement of mean horizontal candle-power with the lamps in rotation at 180 revolutions per minute. There is no photometric apparatus made which can be satisfactorily and continuously used for the measurement adopted by the National Electric Light Association, and if there were, the indefiniteness of the conclusions reached leaves much to be desired.

CANDLE-POWER TAKEN.	CANDLE-POWER.				
	Single U-shaped Filament.	Single Curl Filament.	Long Curl Anchored Filament.	Double Filament.	Double Coil Filament.
(*a*) At 180 revs. with axis vertical	16	16	16	16	16
(*b*) Mean horizontal (standard method)	15·8	16·2	16·6	16·0	15·72
(*c*) Mean horizontal (from plotted values	16·0	16·7	16·7	16·1	15·6
(*d*) Mean spherical (standard method)	12·7	13·5	13·75	13·2	13·8
(*e*) Mean with axis at 45°	10·5	12·0	11·7	12·0	14·0
(*f*) Mean hemispherical	14·3	14·5	14·6	14·0	14·5
(*g*) Mean within 30° from tip	8·7	10·3	8·7	7·9	10·9
(*h*) From the tip	5·7	8·35	7·05	4·8	10·1

FIG. 9.—Candle-power of lamps with different forms of filaments.

In *Fig. 9* I have set down a number of candle-power values for each of the five lamps of which some data was given in *Figs. 4* to *8*, inclusive. Each of these gives a value of candle-power by which the lamp might be called. The values were procured as follows: A lamp was set at 16 candle-power when rotating at 180 revolutions per minute with the lamp axis vertical, in the common arbitrary method, and for all measurements involved in the other tabulated values was held at that voltage. Values in line *b* were determined by taking the average of twelve readings as the lamp is turned, beginning with its standard position and at every succeeding 30°. Values in line *c* are computed from the curves in *Figs. 4* to *8* which take account of all horizontal candle-power variations. The line of mean spherical candle-powers is computed by the Franklin In-

stitute method. Notice how much less the real average is than the rated candle-power in each case and how this average compares with the rated value for each type of filament. Line *e* gives the candle-power these lamps should have been marked if rated by the National Electric Light Association's standard. The readings are not by a rotating socket, but averaged from readings made individually from the lamps tilted at the right angle. It will be noted that this agrees poorly with the value of mean spherical candle-power and bears no easy numerical relation to it. Line *f* of the mean hemispherical candle-power is to be compared with the spherical candle-power values, and this in turn with the line *g*, in which average candle-power is included every ray of really useful light. Line *h* is set down for comparison and to mention later. With such an array of candle-power values for each lamp, what is its candle-power?

WHAT SHOULD A 16 CANDLE-POWER LAMP BE?

Earlier it has been pretty thoroughly explained that the only sensible candle-power by which to call an incandescent lamp is that which is useful in producing illumination at desired points. Such a method has never been used in marking incandescent lamps for sale. It is strange how precedent binds us in everything we do. Here in the matter of incandescent lamp candle-power we are all tied to methods of designation which look back to photometric methods used for gas burners. True, mean spherical candle-power and rotation methods are distinctively electrical, but they first came to be of importance because incandescent lamps are so commonly placed in positions impossible to gas burners; and the rotation methods are used simply to save time in measurement, one reading taking the place of a dozen. It has already been explained that mean spherical candle-power is an impossible measurement for commercial purposes. Rotation methods are poor, too. Not only does the speed of rotation affect the result procured, but some of the best modern lamps produce such a flicker at the car of the photometer when rotated at standard speed (180 revolu-

tions) that not only is the making of an observation most trying to the eyes, but the observer can only make a rough guess for the position of his screen when a balance is obtained. A recent suggestion to choose such a speed for each lamp as just removes the flicker is impractical, also; for not only does it require an adjustment of speed with different lamps, but with many filaments high speed of rotation distorts the filament or even throws it against the glass, due to centrifugal forces brought into operation by the high speed.

What more rational, then, than to measure the lamp's candle-power looking in at the end? It is the light coming from the end which we make use of—which we are interested in. Then this is the light to measure, and that by which the lamp should be rated. Lamps measured thus are as comparable with each other as lamps measured any other way. The apparatus required to make the measurement would be very simple, for no rotating device would be required and the lamp need only be inserted in the socket without any care as to which side comes uppermost when its candle-power is determined, since the candle-power must always be read the same. Thus, readings of different observers would agree without respect to anything involved in the measurement, except the standards used and the personal element, which never can be eliminated. Such a radical change of method, however sensible the change, could not be made without the sanction and support of some of the large associations of electrical engineers. In the meantime, however, for eventually this method must certainly come to be used, all *lamp users* should, in addition to a measurement of candle-power in the conventional way to check up the lamps purchased, take a reading of the useful light out from the tip.

A 16 candle-power lamp should be one giving 16 candle-power from the tipped end. The horizontal candle-power might be considerably less and be irregular in different directions without altering the real value of the lamp. An ideal 16 candle-power lamp would perhaps be one which measures 16 candle-power from the tipped end, had 16 can-

dle-power as the mean horizontal candle-power, and was of nearly 16 candle-power mean spherical. Such a lamp could be turned into any position in an electrolier and still give an illumination equally as good as before and as well distributed.

In most lighting, also, the end of the lamp which has been called the tipped end all along should be tipless. Hold a piece of white paper below an ordinary tipped lamp hung with the tip down, as it commonly is, and the reason is unnecessary to state. Variations in thickness of glass and shadow cast by the tip make lines of light and shade that spoil all real value of light procured.

Watts Based on Candle-Power, as Stated.	Watts per Candle-Power.				
	Single U-shaped Filament.	Single Curl Filament.	Long Curl Anchored Filament.	Double Filament.	Double Coil Filament.
(*k*) At 180 revs. with axis vertical .	3·5	3·5	3·5	3·5	3·5
(*l*) Mean horizontal (standard method)	3·54	3·45	3·37	3·50	3·56
(*m*) Mean with axis at 45°	5·33	4·66	4·79	4·66	4 00
(*n*) Mean spherical	4·40	4·15	4·07	4·23	4·07
(*o*) Mean hemispherical	3·92	3·86	3·83	4 00	3·86
(*p*) Mean within 30° of tip	6·44	5·44	6·44	7·09	5·14
(*q*) From the tip	9·82	6·71	7 95	11·70	5·54

Fig. 10.—Watts per candle-power of 16 candle-power incandescent lamps on basis of different candle-power ratings.

Since the making of such lamps as these is doubtless but a choice of filament form and arrangement, let us hope it will not be long until there are some ideal lamps available commercially.

WHAT IS A 3·5-WATT LAMP?

So far no word as to the efficiency of lamps has been said. It does not directly affect the candle-power nor distribution of candle power. All the lamps mentioned above, for instance, were 3·5-watt 16 candle-power lamps. But why are they 3·5 watts per candle-power? Each lamp used

burned with a consumption of 56 watts. The efficiency or watts per candle-power is strikingly varied by the candle-power to which reference is made. In *Fig. 10* are set down the efficiencies of each lamp of the five types, calculated on the basis of the candle-power values in *Fig. 9*. A 3·5-watt lamp turns out to be one which uses this much electric power per candle-power if this is reckoned at its highest value, the mean horizontal. What a terrible inefficiency these lamps have if we calculate the watts per candle-power from the useful light or the light from their tips!

Type of Filament.	Cost of Current per 16 Candle-Power of Useful Light and per 500 Hours Service.
Single U-shaped	$9.43
Single curl	6.44
Long curl, anchored	7.62
Double	11.20
Double coil, tipless	5.32
Double coil (10 caudle-power mean horizontal)	4.10

FIG. 11.

Lines *p* and *q* of *Fig. 10* give this. Lamps 2 and 5 are the only ones whose efficiency reckoned in a rational way is at all reasonable. The lamps of *Fig. 10* all were supposed to have the same average life and would not be very far different in maintenance of candle-power during life. If a lamp can be made which gives 16 candle-power out from the tip and burns at 5 watts per candle-power, we will have a lamp which is better than any now made. If its life is as good as the present 3·5-watt lamps, it would be a much better lamp than any we have now for all commercial usage. Keeping, however, to lamps now made, the table of *Fig. 11* gives the relative cost of current per 16 candle-power of useful light (light from the end) from each of the five different filament types now made. The computation is on the basis of 12 cents per kilowatt hour for electrical energy,

and the cost is per 500 hours of burning (the average life of a lamp).

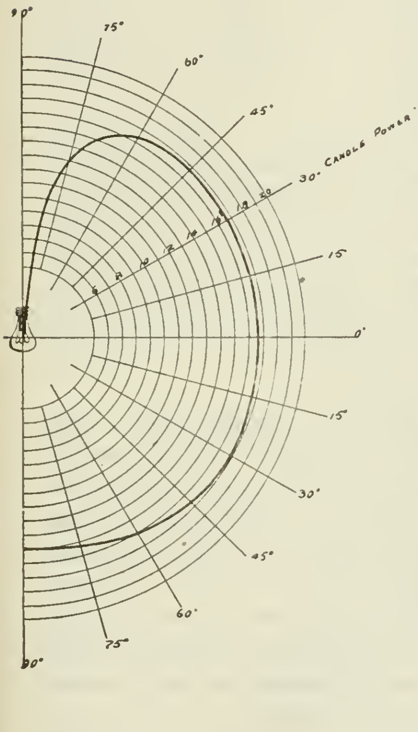
Since we only use electric current in incandescent lamps for the light we get, and since it is the cost of the light which is the vital, commercial problem, the table needs no comments to show which filament types are best; that is, which ones are most economical to use. I have put lowest in the table the cost of current per 16 candle-power of useful light from a standard 10 candle-power (mean horizontal) double coil filament lamp. This lamp gives 8·2 candle-power out from the tip. It is worth noting that a 10 candle-power lamp (so called), with this type of filament, gives as much candle-power out from the tip as any one of the other types which are rated at 16 candle-power. Hence, such a lamp using only 35 watts gives as much useful light as any of the other four types which require 56 watts.

A NEW FORM OF FILAMENT.

Since making the preceding tests there have been developments which are worthy of especial mention. A new type of filament for commercial lighting has come into being. The following matter describes its interesting features.

The Shelby filament, which is the most recent product of that company, has been designed and arranged especially to produce a high candle-power in the vertical direction. In *Fig. 12* is shown the average vertical distribution of candle-power from the new lamp. I call attention first to the arrangement of the diagram; I show the base of the lamp upwards, exactly contrary to the conventional arrangement of vertical candle-power diagrams since 1885. This method of plotting is natural and suggests at once the value of large candle-power downward (below the lamp). It is another step away from the conventions introduced into incandescent photometry long ago from gas photometer practice. I call attention next to the sort of filament and bulb tested; the rude sketch at the center of the diagram only suggests it. The filament itself is a good deal like

the old Shelby coil (see *Fig. 8* preceding), but with the circular coils flattened vertically, so that a much greater projected length of filament shows from the end. The bulb also is much flatter at the end than in other standard forms, and the light comes through it nearly at right angles to the glass. The lamps for which data are given were made tipless. The loss of light through the tips of lamps



SHELBY FILAMENT.

Curve of vertical distribution of candle-power.

This lamp burned at 116·3 volts using 61·6 watts.

Mean horizontal candle-power . (At 180 R. P. M., 16·0.)	16·6
Mean vertical candle-power . .	14·9
Mean spherical candle-power . .	16·1
Mean with axis at 45°	16·5
Mean hemispherical candle-power	16·6

EFFICIENCIES.

Watts per candle-power reckoned on horizontal candle power .	3·72
Watts per candle-power reckoned on vertical candle-power . .	4·13
Watts per candle-power reckoned on spherical candle-power .	3·83
Cost of current per 16 candle-power useful light and per 500 hours of burning, at 12 cents per kilowatt hour . . .	$3.97

having filaments so spreading as these would be very slight.

In the diagram there is to be noted a wonderfully maintained candle-power as one passes from the horizontal to the vertical direction. The lamp as I received it was one of a lot, none of which was marked for voltage, and I set it at 16 candle-power when rotating in the usual way, and made all subsequent measurements at the voltage so deter-

mined. The results set down are therefore on my rating, not on the manufacturers'. To understand the real meaning of the test data set down beside the curve of vertical distribution, comparisons must be made with similar values in the preceding part of this paper. The vertical candle-power (almost 15) is beyond comparison with that given by all filament forms except the double coil, which it even excels by 37 per cent. The mean spherical candle-power is also remarkable. The highest I know of in lamps rated in similar manner is below 14. A glance at the table of efficiencies of *Fig. 10* shows by comparison with figures here the economy of the lamps.

It may seem strange that a horizontal distribution is omitted in the test. This is purposely done. Regularity or irregularity of candle-power in the horizontal direction is quite unimportant compared with the vertical. The average horizontal is shown in the vertical plot, and beyond this it is quite unnecessary to go, for all we need care to know of an incandescent lamp as regards its candle-power is (1) what is the vertical candle-power, and (2) what ratio between this and the average horizontal.

A second test was made on a 10 candle-power lamp having the same form of bulb and filament. It was treated and rated in precisely similar ways to those used with the 16 candle-power lamps. A tabulation below shows the results procured. While the lamp had a lower efficiency than the 16 candle-power lamp, it shows the same general characteristics. The vertical candle-power is 86 per cent. of the horizontal, and by the National Electric Light Association's rating it would be of almost as high candle-power as if rated by the usual manufacturers' rotating method.

10 CANDLE-POWER SHELBY FILAMENT.

CANDLE-POWER.

Vertical candle-power	8·7
Mean horizontal candle-power	10·06
Mean spherical candle-power	9·78
Mean with axis at 45°	9·87
Mean hemispherical	10·05

EFFICIENCIES.

(Watts per candle-power.)

On vertical candle-power	4·7
On horizontal candle-power	4·05
On spherical candle-power	4·17

Cost of current per 16 candle-power useful light and per 500 hours service, $4.50.

The above lamp used 41·8 watts at 112·35 volts.

I take it that the production of such a filament, such vertical candle-powers and such efficiencies as these are evidence of a demand for lamps of the sort. I cannot but feel that a new era in incandescent lighting has dawned when this is so. In future lamp specifications we may look to see a requirement set down as regards the vertical candle-power of lamps, and the ratio of this to the mean horizontal. In fact, it cannot be long before specifications for lamps for commercial lighting will ask for a certain vertical candle-power, and watts per candle-power on this rating, with a requirement as to a minimum horizontal intensity.

DISCUSSION.

MR. W. C. L. EGLIN, of the Philadelphia Electric Company, presented a reflector lamp, which, he explained, was made on the same lines as the Shelby lamp described in the paper, but with the effect magnified. The light from this lamp was wholly through the end, and he claimed for it an efficiency of 1·5 watts per candle-power in the direction the light was thrown. He further stated that the coil form of filament was old, having been used in some of Mr. Edison's early lamps. Mr. Eglin went on to say that the light out horizontally from an incandescent lamp, which strikes the walls, is important and necessary in producing good illumination, and so the horizontal candle-power should be considered. He attached no great value to initial measurements, and questioned the life and maintenance of candle-power of the Shelby coil filament.

MR. FRANCIS HEAD, of the Union Traction Company, in reply, stated that he had carried a number of such coiled

filaments through a life test, and they had proved fully equal to any of the other makes.

PROF. ARTHUR J. ROWLAND, author of the paper, said that the paper carefully avoided the question of life and maintenance of candle-power, since the intention was to deal wholly with light distribution. The light distribution must remain the same throughout the life of any lamp, without respect to decrease in candle-power. He admitted that the coiled filament in the old type Shelby lamp was not new, and called especial attention to the circumstance that the advantages it gave had never been observed, for this form alone gives a good candle-power distribution. He further said that the light out to the walls was, of course, a good thing, in order to have them properly illuminated; also, that the light reflected from them may be of a little use when the lamps in service give but low candle-power out from the end opposite the base. As a matter of fact, the useful illumination produced by light reflected from the walls is almost negligible, since it has to pass through the long distance to the walls and back again. Its only value is to break up shadows and aid diffusion, as shown numerically in the paper. Moreover, if this kind of light is useful, the Shelby coil filament has as much light to send out to light walls and for reflection as any other, while the direct light from it is much greater. A reflector lamp has use in certain specific instances: for example, to supplement general lighting over a desk when it takes the place of a lamp with such a reflector as a McCleary shade. It is not practical for commercial lighting, however, since it limits the light absolutely to the direction in which the reflector sends it, and produces strong, sharp shadows.

REFLECTOR LAMPS.

Compared with others in preceding paper by Prof. Arthur J. Rowland.

There is nothing new in reflector lamps; they were introduced into this country some years ago by a foreign manufacturer, and more recently have been produced by several American manufacturers, and classed with their special

lamps. Very recently the General Electric Company has brought out a reflector lamp of the same general style as those which preceded it.

For certain purposes a reflector lamp is useful. It may supplement general illumination and give concentrated light to advantage where this is desired, but it cannot be successfully used for commercial lighting for several reasons.

The light is all directed one way and absolutely cut off from every other direction. This gives one a bright spot of light under the lamp, but dark spaces between, around and above them—quite dark except for reflection from the few objects illuminated. Nothing can be more trying to the eyes than to look from brightly lighted objects to those not lighted at all and back again.

An ordinary reflector lamp, acknowledged to consume 50 watts, is extravagantly used for lighting even though the efficiency may be 1·5 watts per candle-power in the direction in which the light is thrown, for the reason that it illuminates only a small area. With it general illumination would be necessary at additional cost.

A reflector lamp combines a reflector and a lamp in one. While the combination may cost less than lamp and reflector bought separately, when the filament burns out the reflector is gone too; hence, at the price these lamps are offered, they are too expensive for general use. Separate reflectors are much to be preferred where it is really necessary to use them.

In comparison with other lamps which are used regularly in commercial lighting, the reflector lamp suffers. It gives no horizontal light at all, and the importance of a certain amount of this light is recognized by all good lighting engineers. Any lamp which gives enough light in the vertical direction to be economical, and gives light out besides in the directions which assist general lighting and diffusion, is far superior to a reflector lamp. It is found that the old double coil filament has these features, but it is greatly exceeded by the new Shelby coil, as is shown by photometric tests.

Whether a lamp which gives 16 candle-power horizontal

and 16 candle-power vertical is better than one which gives 6 candle-power horizontal and 16 candle-power vertical is an open question. Every one must agree that there is some limit below which the horizontal candle-power of a lamp should not be decreased, and this is before the zero point is reached.

If reflectors over lights to throw the whole light flux in the vertical direction are necessary for any sort of lighting, that lamp is best which uses a form of filament giving high candle-power in the vertical direction without the reflector. By reflection one adds only to the direct light. Of two lamps having a given light flux to reflect, that one having most initial candle-power in the direct rays will have the brightest light after a reflector is put in place. A Shelby coil filament turns out then to be better than any other form when used with a reflector or shade as well as without.

Stated Meeting, held Wednesday, May 9, 1900.

ALUMINUM:

CONSIDERED PRACTICALLY IN RELATION TO ITS GENERAL APPLICATION IN THE ARTS AND MECHANICS.

By Joseph A. Steinmetz,
Member of the Institute.

"As light as air! As bright as silver! Impossible of tarnish! As strong as steel! Cheap as clay!

"The great new white metal aluminum. Houses, bridges and locomotives to be built of it. Iron and steel, metals of the past; with the great 'Aluminum Age' drawing upon us."

Such picturesque and startling remarks were not at all uncommon ten years ago, and even more recently in the most prominent local papers and technical journals.

To the unthinking mind, it was perhaps quite believable that aluminum, the laboratory curiosity costing dollars per ounce, should excite wild dreams of coming wonders when, almost over night, the discovery and successful application

of the electrolytic methods of reduction put the price of this unknown metal to almost as many cents per pound.

But nothing could have contributed more to its disadvantage and disaster of its industrial development. Years of time and tons of samples have not yet served to disillusionize the world of these disastrous notions, and hundreds of thousands of dollars have been ruthlessly wasted in trying to force the metal to perform impossible services, devoid of wisdom or foresight.

The purpose of this paper is to briefly enumerate those uses of aluminum that have proved satisfactory and extensive, with the view of encouraging further applications along kindred lines, and to speak a word of caution regarding improper uses of the metal, so that disaster may be avoided, and to save aluminum from further damage to its chemical and physical reputation. From the fact that the aluminum output is almost doubling from year to year, it is almost as impossible to cover the uses of the metal in detail as it would to trace the myriad uses or applications of any particular metal, such as silver, copper, brass, zinc, tin-plate or galvanized iron.

A satisfactory classification is nearly impossible, hence the thousand and one uses of the metal will be jotted down in a running list as the suggestions come to mind.

Upon the use of aluminum in the metallurgy of steel we will not dwell, save to briefly remark that for this purpose many hundreds of tons of metal are annually consumed.

The aluminum is added to molten steel in proportions of a few ounces to the ton of steel, in the making of ingots and billets.

Larger tonnages are treated in the process of making steel castings by adding the aluminum to the molten mass before pouring. It has also been found of great advantage, to insure the making of a perfect casting, to insert small scraps of aluminum in the mould at such places and corners and cores where difficulties threaten.

Many tons of aluminum are yearly used for the making of patterns. This is indeed a most correct use to replace the old heavy brass gates of patterns with the light-weight

aluminum, stiffened with about 5 per cent. of zinc and a like amount of copper. The advantages of these light-weight patterns are manifest. The men at the benches can mould more forms in a given time and with less fatigue. The patterns, weighing but one-third as much as brass, can be handled and stored more readily and cheaply. The express charges upon return of patterns are greatly reduced —an item of considerable magnitude in an active foundry.

Immediately the very large use of aluminum suggests itself for models and salesmen's samples. Particularly will the hardware traveler see the boon of this, and many of our largest houses have full lines of salesmen's samples, replacing the old line of ironwork or nickel-plated brass, at a reduction of 60 per cent. of weight, and of no increase of cost.

Not long ago a large foundry of Wilmington, and, later, a Philadelphia foundry, had some large iron castings to make, the yokes of cable roads, great iron pieces spreading the full width of the track and supporting the rails, and carrying in their middle the conduit through which the cable ran. These castings were made from wooden patterns, which caused much trouble by chafing and wearing in the sand, and warping and springing out of alignment. At the suggestion of the writer these patterns were duplicated in aluminum, and all difficulties were thus transformed into unpleasant memories, and the work fell out good and sound and true.

Until recently aluminum has not been employed as an active competitor of brass and copper on account of its higher comparative price, but to-day aluminum is cheaper than copper, considered bulk for bulk. Copper is three and one-third times heavier than aluminum. Taking, therefore, copper at its present market price, and increasing by this factor, it will appear that aluminum is cheaper, a fact which should open many channels of new application for aluminum.

One thing that has figured seriously to the disadvantage of aluminum, and, indeed, has quite precluded it from many excellent fields of use, is the lack of a good, cheap, easily-worked and permanent solder.

It is true that there is a most excellent solder upon the market, invented by Mr. Joseph Richards, of your Institute, but this solder is difficult to apply, and it is frequently beyond the ability of the ordinary tinsmith to secure a satisfactory joint.

There are several reasons for this lack of success. Not keeping the work hot is the chief cause of the solder mushing and making a rough, dirty seam. It is very often true that the peculiar pattern or intricate design of the piece makes it impossible to keep the work hot at the points to be soldered. Then, too, the quick formation of a film of oxide upon the aluminum, unless removed by scratching or filing, figures to the disadvantage of a solder by not permitting it to take a firm hold upon the parts to be joined.

Wherever possible, then, it is earnestly suggested to make joints by crimping or lock-seaming or by riveting, or, better yet, to avoid all joints by spinning or drawing up the shape to be made, whenever its contour will permit of such practice.

The old saying that "the best joint is no joint at all" holds good here conspicuously.

A few remarks relative to the growth of the aluminum industry, with comparative figures, will prove of interest.

The following table shows the aluminum production of the United States and of the world, expressed in metric tons (2,000 pounds):

	U. S.	World.	Per Cent. in U.S.
1889	21·6	70·9	30
1890	27·9	165·3	17
1891	68·2	233·4	29
1892	118·1	487·2	24
1893	154·4	716·0	22
1894	250·0	1,240·9	21
1895	417·3	1,418·2	29
1896	590·9	1,659·7	36
1897	1,814·4	3,394·4	53
1898	2,358·7	4,500·0 (est.)	52
1899	2,948·4	6,000·0 (est.)	49
1900	4,000·0 (est.)	7,500·0 (est.)	53

Those returns marked estimated (est.) are the best which can be conjectured from available data. The aluminum in-

dustry is growing most rapidly in France and in the United States. Canada will enter the list of producing countries next year, with a plant of 5,000 horse-power, and will add 1,000 tons each year to the world's output.

Presuming that the total amount of aluminum produced last year was used for the specific purpose of electric conductors, then the 6,000 tons of aluminum would displace 12,000 tons of copper, or a like amount of aluminum sheet would be equivalent to 20,000 tons of sheet copper, were the specification for culinary and cooking utensils.

These comparative figures emphasize the important position that the metal has assumed.

Considering the United States alone, of the metals produced here in 1898, only pig iron, copper, lead and zinc were produced in greater quantity than aluminum, and only these, with the addition of gold and silver, surpassed it in the value of the output.

If we desire to manufacture a given object of metal, we can make it cheaper in aluminum than in anything else, excepting iron, lead or zinc, to which might be added, among composite metals, tinned and galvanized iron.

These are the only metals left for aluminum to compete with, and its greatest struggle in the future will be against tinned and galvanized iron. Dr. Richards believes that when the market price of aluminum reaches 15 cents per pound (probably in the next decade), it will compete actively with these common metals, and by 1925, when it will probably reach 10 cents per pound, its only practical rival will be steel.

The middle of the twentieth century will see steel and aluminum standing side by side as the most useful of the useful metals, aluminum having by that time developed many peculiar alloys enhancing its physical properties and largely increasing its field of application.

The plants now producing aluminum are those of the Pittsburg Reduction Company, at New Kensington, Pa., and Niagara Falls, New York; the British Aluminum Company, of England; the Aluminium Industrie Actien Gesellschaft, at Neuhausen, at the Falls of the Rhine, in Switzerland; the

Société Électrometallurgique Française, at La Praz; the Société Industrielle de l'Aluminium, at St. Michel, in France.

There are also several large plants projected and in course of construction, notably upon the St. Lawrence River, in Canada, and at Rheinfelden and Salzburg, in Germany.

The Hall patents under which the Pittsburg Companies are producing expire in 1906, and by that time other competitors will be actively engaged in adding to the domestic tonnage.

Then, too, it is more than likely that attempts to repeal the import duty of 8 cents per pound will soon be made, as this duty is no longer necessary for the protection of our infant industry, particularly in view of the fact that a large percentage of the aluminum produced in this country is exported to Europe, leaving the supply of metal at home quite inadequate for domestic needs.

Some years ago, when aluminum was thrice its present cost, the proprietor of a certain brass foundry in Philadelphia had the courage to back up his convictions that the metal was ideally suited for bath-tub work.

Some years even before this, a maker of bath-tubs had attempted its use in sheets for this purpose, by lining the old wood-box tub with aluminum sheets joined by crimping and soldering. They had to abandon the project after repeated failures to secure a tight seam and joint, lacking a solder that was easy to work, and that would readily run out a long seam.

These same lines were unsuccessfully attempted by other bath-tub makers, who had met with some encouragement by avoiding the soldered seam by flanging the sheets and clamping the edges thus formed between an iron frame, which acted as the support to the basin body.

The brass foundry previously mentioned followed radically different lines and made a single sand casting of the complete tub with its roll rim, the same pattern as we now see in enamelled iron, upon which it is almost impossible to improve, unless perhaps by a stamped sheet-steel tub or one of moulded glass.

This cast tub weighed about 150 pounds, and the rough sand casting was ground smooth upon the inside and around the rim by use of an emery wheel upon a flexible shaft, after which the tub was polished bright upon a rag buffing wheel.

A perfect casting was difficult to obtain, due to blow-holes and shrinkage cracks and sinks, and the difficulty of this piece done in practically pure aluminum can well be appreciated by those familiar with foundry practice.

The effect thus obtained was decidedly brilliant, and most pleasing, but the tub failed ignominiously in the test of time and use. The alkali of the soaps utterly destroyed the luster of the finish, and ate deeply into the body of the metal, marring and pitting it beyond measure. Thus it came about that another use for aluminum became impossible of realization.

The same general observations apply to the large list of plumbing fixtures of aluminum evolved at about this time, such as faucets, chains, handles, soap-dishes, basins, and many standard shapes in nickel-plated brass, which were quickly retired as brief experience proved their worthlessness.

A most excellent use for aluminum is found in the making of steam-jacketed kettles and cauldrons for boiling of syrups, fruit juices, honey and wax, as well also as for certain acid work for which the peculiar chemical properties of the metal specially adapt it.

An example of this might be cited in Mr. Levy's nitric acid atomizer for zinc etching, a great improvement over the old acid bath for obtaining quick action in making etched plates for printing. There has recently been completed by a coppersmith of Newark one of the largest aluminum kettles ever constructed; the hemispherical bottom or bowl measuring 51 inches across its diameter with its flanged edge, and 30 inches deep, was cold hammered and formed up out of a flat circle 68 inches in diameter, and the upper band or tubular body was curved around out of a flat sheet measuring 13 feet 8 inches long by 14 inches wide. The kettle was hammered out of ¼-inch stock, and the bowl

was much more readily shaped and more responsive to the tools than even copper.

The purpose of these large boiling kettles is for melting wax for the cylinders of the Edison Company's phonographs, as the wax cylinder material seemed to attack iron and copper kettles, whereas the aluminum boilers are entirely unaffected.

In the electrical field aluminum is forging ahead rapidly into significant prominence.

It was singularly opportune for its introduction for electrical purposes that the price of copper advanced just at that time when the processes of making aluminum in increased quantities and at reduced figures of cost had been satisfactorily installed, and when new uses and new fields were being eagerly sought; for immediately many careful experiments were undertaken to determine the possibility of substituting aluminum for copper, and these investigations promise to produce most encouraging results. Comparative tests are now being made by the Chicago Fire Alarm Service between copper wire and aluminum. Number 10 wire was used and the preliminary tests before erections showed that the tensile strength of the copper wire was greater, size for size, but not so great weight for weight. The copper wire showed a greater elongation and endured without rupture a greater number of twists—in fact, twice as many as aluminum.

To secure further data under the actual service conditions, the Chicago line will be given a winter's test, and has been strung in the stormiest section of the city, and where it will also be subject to the smoke and gaseous fumes arising from the locomotives passing in that section. The results of this service test will be made the subject of a report this spring by City Electrician E. B. Ellicott, of Chicago, to his Board.

The Western Union Company has several miles of aluminum wire in use now for over two years, and is carefully compiling the physical data necessary for a consideration as to its merits in comparison with copper and iron.

A very interesting report relating to the "Tests and Cal-

culations for a Forty-Mile Aluminum Wire Transmission Line," by Mr. E. A. Perrine, as erected and conducted by the Standard Electric Company, of California, is printed at length in the *Aluminum World* of November, 1899.

General Greeley, chief of the Signal Branch of the U. S. Army, had several outfits of aluminum portable field lines in use in Cuba during the recent war, and he reports that they were very satisfactory and particularly advantageous, owing to the light weight of the coils of aluminum wire.

The main electric conductors in use at the reduction works at Niagara Falls are made of large aluminum bars many square inches in area, and have been giving satisfactory service for years.

To some extent aluminum has been used for commutator segments, but the difficulty in wiring up due to the different metals in contact caused serious discouragements. Blades for switchboards have been successfully manufactured.

The advantages of aluminum for use in the making of culinary and cooking utensils were early recognized, and the new metal bids fair to excel copper in this line of development; in fact, many hundred tons annually are now consumed in the successful manufacture of such articles.

The early exploitation of this field was most discouraging, owing to the fact that the manufacturers of cooking utensils understood the peculiarities of the metal no better than the consumers who purchased the articles for use, and the utensils were generally seriously abused, battered and neglected, the universal idea being that aluminum was quite indestructible, no matter how abominably treated. The utensils were allowed to take care of themselves; they were ground and scratched with sand-soap and often washed in lye, which, being one of the solvents of the metal, caused rapid disintegration.

These early attempts to introduce aluminum cooking utensils were made at a time, several years ago, when copper was less expensive, and when enamelled iron and tinned and steel articles were infinitely cheaper.

These adverse circumstances tended seriously to the retirement of aluminum from this field, but later develop-

ments, such as the fall in price of aluminum, and the heroic efforts of our pioneer manufacturers quickly regained the ground thus lost, and forged rapidly ahead to well-merited success, for now aluminum cooking utensils, household articles and culinary shapes, for home, institutions and hospitals; field equipments for the army and outfits for the navy, and the innumerable uses heretofore supplied by copper, tin sheets and enamelled iron are divided with aluminum, and the new metal bids fair to win first honors.

Among some of the advantages possessed by aluminum over the other metals might be cited its higher heat conductivity; its light weight, bulk for bulk; the fact that it creates no poisonous salts or oxides when used in the preparation of fruits and vegetables and other possible combinations dangerous with copper or tin.

A very large use of aluminum in forms of caps and covers, stamped out of sheet metal for sealing catsup, mustard, fruit, jams and jellies, and various lines of such goods, has been lately developed, the advantage of price and absence of dangerous corrosion or acid action making aluminum an ideal metal for these purposes.

In Europe the peculiar advantages of aluminum have been recognized for a much longer time than in America, and a number of the largest manufacturers in England and on the continent are making complete lines of utensils.

The recent South African war has created a tremendous demand for aluminum field cooking and messing outfits, thus spreading the fame of aluminum and knowledge of its advantages for portable gear among a class of men who will understand and appreciate them.

A most interesting account of the British army equipment will be found in the March number of *Aluminum World*, of the current year.

The German army, as well as the field forces of other continental powers, are thoroughly equipped with aluminum, and the dead weight per man of superfluous ornamentation and equipment has been considerably reduced, tending greatly to increased efficiency as a fighting unit.

In the recent Arctic explorations, in the gold-seeking ex-

peditions into the Klondike and Alaska, in the journeys into the Dark Continent, aluminum equipment has played a prominent part; Mr. Wellman built aluminum sledges for transporting his supplies over the ice; the Alaskan gold miners took in many light camping and cooking outfits, and Dr. Carl Peters had with his expedition an aluminum steam launch in portable sections.

Five years ago the well-known shipbuilding firm of Yarrow & Co., of England, built the first aluminum torpedo boat, and while a second craft of this description has not been since constructed so generally of aluminum, yet two of the latest additions to our navy, the torpedo boats "Craven" and "Dahlgren," have their observation towers, hatch covers, galleys, cowls and many minor parts made of aluminum.

These boats were built by the Bath Iron Works, of Maine, and the aluminum details of construction, embracing the use of rolled angles and structural shapes, plates and riveted work, were conceived with the approval of Chief Constructor Philip Hichborn, of the United States Navy, who looks forward with interest to the tests of time and the wear and tear of service to demonstrate the practicability and adaptability of aluminum for ship construction and fittings.

The American sloop yacht "Defender" was built of aluminum plates from water line to deck level, the submerged plating being of bronze, which arrangement tended to considerably lower her center of gravity, insuring increased stability.

These aluminum plates, which were carefully and thoroughly painted, gave good satisfaction and are still in service. Certain plates in the stern had to be replaced, as well also as smaller parts and fitting, due to corrosion and electrolytic action and wear and tear.

In general this application was highly satisfactory and encouraging.

Aluminum powder and thin beaten leaf are now largely used for securing decorative effects in the arts, as silver paint, and for printing and bookbinding, having

almost entirely replaced the silver bullion leaf formerly used.

The powder is also mixed in the form of a paste for ink for printing coarse cotton tinsel fabrics, in gaudy design for Oriental trade.

A paint called in the trade pegamoid, aluminoid, or aluminum bronze paint, is largely used for coating architectural ironwork, lamp-posts, letter-boxes, elevator grilles, and cages, and kindred applications, and has proved highly satisfactory.

Overtures have been made to the Public Building Commissioners to paint the outside of the Philadelphia City Hall Tower, to restore it to an aluminum luster as originally intended, and far brighter and more durable than the dismal slate-blue of the unknown electro deposit now upon the ironwork.

Aluminum powder has found an excellent and successful use as a mixture for making photographic flashlights, being cheaper than magnesium and devoid of the pungent odor or unpleasant smoke incident to the combustion of the old magnesium powder.

A recently developed and tremendously successful application of aluminum is in flat, smooth plates for use in lithographic printing. The thin aluminum plates make excellent impressions and are quickly replacing the old heavy lithographic stones, one of the great advantages of aluminum being due to the possibility of its application to the rotary press, as well, also, as to its lower cost.

Aluminum hair pins are being made by the million, thus disposing of a goodly weight of wire. These hair pins give excellent satisfaction, and have been well received by the trade, who report a steady and increasing demand.

Thimbles by the thousands of gross are made by several concerns in the United States and abroad, and several tons of sheet aluminum are yearly thus employed. The metal, however, is rather soft for this purpose, as the hard steel needle soon perforates the thin aluminum shell.

For ferrules and ornamental bands, for canes and umbrellas, the metal has been successfully applied.

A large use of aluminum has developed for making metal combs, brush backs, mirror frames, and a host of toilet and fancy articles, useful as well as ornamental.

In fact, it is quite impossible to enumerate the myriad articles now being made of aluminum. One might as well make up a list of everything so far manufactured out of sheet or wire in brass, copper or nickel, tin sheets, steel and iron, and such combinations thereof, as form the materials out of which all known metal devices have thus far been manufactured, for aluminum is quietly, steadily and surely encroaching upon the domain of the metals mentioned, and with the development of its special alloys this march of conquest will proceed with ever-increasing acceleration.

The metal lends itself readily to working in the minting dies, and many very pleasing and durable effects have been obtained. Many tons of metal are yearly used in the making of coins, medals, checks, tags, religious and commemorative medallions and insignia. Artistic and permanent effects have been obtained in die work and minting by our American pressmen.

In conclusion, a few words quoted from a recent private letter to the writer, from Dr. Joseph W. Richards, who is today one of the best authorities on the subject of the aluminum industry, will be interesting.

In reviewing the wonderful growth of the industry and the success of aluminum, he says: "Is not the prospect gratifying to us who have befriended the metal, so to speak, in its infancy, have mothered it, fathered it, and even wet-nursed the struggling infant with our own substance (*i. e.*, with money out of our own pockets)?"

The brief remarks embodied in this paper and the casual facts herein set forth answer this query heartily in the affirmative.

Mining and Metallurgical Section.

Stated Meeting, held Wednesday, May 9, 1900.

MOVEMENTS OF GROUND WATER.

By Benj. Smith Lyman.

The two reports on the "Principles and Conditions of the Movements of Ground Water," by Prof. F. H. King and Prof. C. S. Slichter, in Part II of the nineteenth annual report of the U. S. Geological Survey (for 1897–98), the two issued also as a separate book of about 320 very large octavo pages, three-fifths by King and two by Slichter, might perhaps more logically have been placed in the opposite order; for Slichter, with his mathematical discussion, summarizes what had been previously ascertained, and sets forth what conclusions may, by pure reasoning, be inferred therefrom, clearing the ground, rooting out certain doubts that otherwise would constantly spring up, and firmly establishing a number of principles; while King's report is in great part taken up with the description of experimental tests and practical applications of the theories. The work of both is important, and it may be worth while to undertake here a brief, connected and easily intelligible summary of the principal valuable practical results, in the absence of what would be preferable, a summary by the authors themselves.

Almost the whole book is taken up with discussing the laws of the movement of water through the pores of the soil and rocks; for the further considerable movement through crevices in rocks or hardened soil is, of course, more irregular and in many respects less capable of reduction to precise laws. The mathematical theories and formulas are abundantly illustrated by examples and by the solution of practical problems and by diagrams.

For the purpose of at least an approximately correct idea of the movements of water through a natural soil made up of grains of various shapes and sizes, Slichter con-

siders an ideal soil of uniform spherical grains with the same "effective size" of grain as the natural ones. Such spheres, when packed in the closest manner possible, would leave about 26 per cent. of pore space, or porosity, in the whole bulk; but the most open arrangement possible with the grains in uniform contact gives a porosity of about 48 per cent. The empty spaces, or pores, for the passage of water between the spheres are, of course, not strictly capillary tubes, straight, circular and uniform in cross-section. But it is shown that the length of the axis of such a passageway is only about 6 per cent. longer than a straight line, even in the case of the closest packing of the spheres; that the triangular pore has a mean section nearly one-half larger than its minimum section, but with the flow only negligibly affected by the variations; that the flow through a circular tube is nearly three-fifths greater than the flow through a triangular tube of the same area of cross-section; and, consequently, that it may be safe to reckon the pore passage as equivalent to a straight circular tube with a cross-section equal in area to the minimum triangular section of the pore.

Poiseuille, in 1842, announced his law of the flow of liquids through capillary tubes, making it proportional to the pressure and to the square of the area of the cross-section and inversely proportional to the length and to the viscosity. A brief, simple formula is therefore now deduced for the quantity of water transmitted in a second through a column of soil of a given height, area of cross-section, mean diameter of soil grains, pressure or head of water and viscosity of the water according to temperature. A very important factor in the formula depends on the porosity of the soil, making the result more than seven times greater for the most porous soils than for the least porous ones, and twice and a half greater for a porosity of 40 per cent. than for one of 30 per cent.

In the case of a sandstone bed 100 feet thick and 100 miles wide, imperviously covered above and below, and having a dip of 5 feet to the mile, a catchment area at the upper end, and a free outlet for the ground water by a

cliff or cut at the lower end, and a mean size of grain 0·15 millimeter, and a porosity of 30 per cent., the formula indicates a flow of about $\frac{9}{10}$ of a cubic foot for each linear foot of the cliff or cut, or to an artesian well 5,000 cubic feet a day; or 100 square miles. of the sandstone could permanently supply only 100 wells of that capacity, leaving open crevices out of account. If the sandstone grain were 0·25 millimeter and the porosity 32 per cent., it would take but 1,500 feet linear to obtain the daily yield of 5,000 cubic feet; and with a grain of 0·5 millimeter and porosity of 32 per cent., only 400 feet linear. But from a rainfall of 36 inches a year, with, say, one-third of it entering the catchment rock, such a daily yield could not on the average be obtained from a space less than $\frac{1}{4}$ of a mile square, even though there be abundant crevices.

The formula was worked out at King's suggestion, and at his suggestion has been used inversely for calculating the "effective size" of the soil grains from the amount of the flow. He found that water did not give very uniform results, because the finer particles of sand were carried along in the current and occasioned more or less clogging or opening of the pores. But using air, with the appropriate coëfficient for its own viscosity, the results have been quite reasonably satisfactory, and much better than those of the method of counting and weighing the grains even when carefully sifted and sorted.

Slichter further shows that a problem in the steady motion of ground water in a uniform soil or rock is mathematically analogous to a problem in the steady flow of heat or electricity, or of a perfect fluid. But in stratified material the vertical motion, aside from the effect of gravity, is apt to differ from the horizontal in ease. Several problems in regard to the horizontal motion are solved and illustrated by interesting diagrams showing the circular, elliptical or hyperbolical paths of the water towards or from wells, sinks or sources, or ditches, or around dams. Then the motion of ground water in vertical planes is mathematically discussed, and it is shown that pressure appar-

ently indicated by the level of the surface of moving ground water may in certain cases be much greater than the real pressure upon the water at a given point below; for example, where the water can freely escape through a neighboring vertical plane, say the wall of a ditch or well.

Several problems of the flow of artesian wells and their mutual interference are mathematically solved. When the well fully penetrates a horizontal water-bearing bed with impervious top and bottom, a formula is obtained for the flux, assuming the bore to be large enough to carry off the water without appreciable resistance. For example, with a 6 inch well through a 100-foot horizontal water-bearing sandstone, with an effective size of grain of 0·15 millimeter and a porosity of 30 per cent. and a temperature of 50° F., when the pressure, or head of water, is 10 feet, from so much lowering the water in the well by pumping, the flux would be about $5\frac{1}{4}$ cubic feet a minute. If the effective size of grain is 0·25 millimeter and the porosity 32 per cent., the flux becomes 18 cubic feet a minute. The formula shows that the yield of a well is directly proportional to the head of water, that is, to the amount the well's water surface has been lowered by pumping, adding, of course, whatever head a flowing artesian well may have without pumping.

If the bore is large enough to carry off the water without appreciable resistance, an increase of the diameter of the well would, by the formula, increase the yield of water but slightly. For instance, if the 6-inch well that yielded 18 cubic feet a minute were increased to 12 inches, the yield would still be less than 20 feet; or if the diameter were reduced to 2 inches, the yield, aside from friction, would be nearly 16 feet. But the friction alone of a 2-inch well 200 feet deep would reduce the yield for the head of 10 feet to less than 6 cubic feet a minute. Friction would reduce the yield of a 4-inch well to about 14 cubic feet a minute, and reduce a 6-inch well to a yield of $17\frac{1}{2}$ feet; but with a diameter of 12 inches the friction would not appreciably lessen the yield.

The pumping of a well and lowering its water surface

reduce the pressure of water in the rock near the well, but chiefly in the immediate neighborhood; for example, if the pressure drops 10 feet in the well, it would fall only 5 feet at the distance of about 12 feet, and then very gradually change to a fall of 1 foot at 275 feet off.

If the well do not fully pass through the water-bearing bed, the formula for the yield must be modified; and it results that the 6-inch well with the yield of 18 feet for 100 feet of depth would, if only 50 feet deep, yield from its sides 9 cubic feet a minute, and from its bottom 5 per cent. additional, or about 9½ cubic feet in all. A well 20 feet in diameter and 22 feet deep in soil of the same coarseness, porosity and temperature as that 6-inch well would yield about 22 cubic feet a minute.

A table is given for the yield of a 6-inch well sunk through a bed 100 feet thick of material of various degrees of coarseness and with various heads of pressure, with porosity 32 per cent., and temperature 50° F.; showing for 0·02-millimeter grains and 4 feet of head a yield of less than five-hundredths of a cubic foot a minute; but for 3-millimeter grains and 20 feet of head a yield of 5,322 cubic feet a minute, leaving well friction out of account.

It is shown with a large illustration how to draw the curved lines of flow into a well in a region where the ground water has a constant motion in a general direction. The mutual interference of two wells is mathematically discussed; and is illustrated with diagrams of the lines of flow, both for wells yielding equally and for one yielding twice as much as the other.

Suppose the water of two wells 10 feet apart to be lowered in each 10 feet by pumping, each well will yield about 34½ per cent. less, owing to the interference; at 100 feet apart, about 20 per cent. less; at 200 feet apart, about 15 per cent. less; at 400 feet apart, about 10 per cent. less; at 1,000 feet apart, about 6 per cent. less. In like manner the interference of three 6-inch wells in a row 5 feet apart would be 55 per cent.; 10 feet apart, about 51 per cent.; and 100 feet apart, about 31 per cent. In other words, two wells 10 feet apart would yield 131 per cent. as much as a single

well; and a third well half way between them would make the total yield only 135 per cent. of the flow of a single well. But if the two wells are 200 feet apart they would together yield 169 per cent. of the flow of a single well; and a third well midway between them would bring the total up to 207 per cent. of the flow of a single well.

From the bottom of the above-mentioned 20-foot well, 22 feet deep, yielding about 22 cubic feet a minute, suppose one, two or three 6-inch wells to be sunk 200 feet into the sandstone. As already seen, one such 6 inch well would yield about 18 cubic feet for a depth of 100 feet, or about 36 cubic feet for a depth of 200 feet, enough, then, to increase the total yield to about 58 cubic feet; but, as the pressure varies inversely as the square of the distance from the large part of the well, making the upper 20 feet or so of the 6 inch well useless or yielding chiefly at the expense of the large well, the total yield would probably be only 54½ cubic feet. Two such 6-inch wells 5 feet apart would in like manner increase the total yield to about 62 cubic feet a minute; or if 10 feet apart, to 64½ cubic feet. Three such 6-inch wells 5 feet apart in a line would bring the total yield up to about 66 cubic feet a minute; but if 10 feet apart, to 71½ cubic feet.

The mutual interference of a large number of wells in a row is also investigated mathematically, and a small table of results is given for 6-inch wells that have had the water surface in each lowered 10 feet by pumping: If 100 feet apart, the interference is nearly 66 per cent.; if 200 feet, 45 per cent.; if 400 feet, 24 per cent.; if 600 feet, 14 per cent.; if 1,000 feet, about 6½ per cent.

The report ends with a bibliography of about eighty important works bearing on the subject.

So much for Slichter's mathematical theories, very valuable and yielding interesting and even surprising results; yet necessarily based on conditions more uniform than can scarcely be found in nature, and so, of course, not to be taken too strictly in application to natural cases.

Now for King's practical observations. He gives 100 pages to a discussion of hundreds of his ingenious and

painstaking experiments with water, with air and sometimes with kerosene passed through sand, sandstone, dust shot, gauze, bundles of knitting needles and capillary tubes, and to a review of the experiences of others, to test the accuracy of Poiseuille's law that the flow is proportional to pressure, the law that was taken as the very foundation of much of the mathematical work. Further on he gives some 300 experiments of his own on the flow of water in a given time through ten grades of quartz sand of different coarseness, illustrated with natural-size pictures of scattered grains not closely packed. The result of the whole is that the flow is often not proportional to the pressure, generally increasing faster than the pressure, sometimes slower, in every case systematically faster or slower; not sometimes one way, sometimes the other, as if from errors of observation. The flow of water has increased faster than the pressure in some trials with sand by nearly 46 per cent.; with rock by nearly 86 per cent.; and with capillary tubes by nearly 21 per cent. The general result in the graded quartz sand experiments was that with the finer grains and low pressures the flow increased faster than the pressure; but with coarser grains the flow increased more slowly than the pressure, because of turbulence in the larger pores. Indeed, the already-known fact of sometimes slower flow had formerly been accounted for by the absorption of energy at the ends or within the body of the tube containing the sample tested. But it is not so easy to understand King's faster increase of flow than of pressure if the viscosity of water and air is really independent of pressure, as inferred by Maxwell. King suggests that the stationary or slowly-moving film of liquid adherent to the walls of the capillary passage may, under high pressure and greater velocity, become thinner, or, in part at least, may be accelerated more rapidly than the pressure increases; so as in effect to increase the diameter of the passage.

He gives the results of 150 conveniently expeditious tests of sands and soils with his fully described aspirator or apparatus for determining the effective size of grain by drawing air through them, and tabulates the results along with

the observed pore space and the rate of movement of the air. The pore space is determined by computation from the weight and specific gravity of the amount required to fill a cylinder of known capacity with the closest packing; that is, with gradual filling and frequent gentle tamping and with gentle jarring at the close. He finds that both the upper and lower theoretical limits of pore space for the ideal soil, about 26 and 48 per cent., as above mentioned, are but slightly exceeded, and that the porosity in all cases lies between 25½ and 53 per cent. The fine-grained elements tend to give a larger pore space than the coarser ones. The smallest pore space results from mixing grains of different size. The simple sands, with well-rounded grains about 0·15 millimeter in diameter, lie close to the mean value.

It is seen, then, that the amount of water stored in saturated soil—that is, below the ground water surface—is, in round numbers, two-fifths of the whole bulk. Usually three-quarters as much is to be found even in soil above the plane of saturation, except during dry times in a surface layer 1 to 5 feet thick. Saturated sandstone may contain as much as 38 per cent. in bulk of water, equivalent to immense and deep lakes in certain widespread level-lying Western sandstones. Even compact marbles and granites contain an appreciable percentage of water. It is probable that water penetrates the earth's crust in some degree to a depth of more than 10,000 feet.

But consolidated and deep-lying rocks have, in growing compact, lost much water. Fine silt deposited in water contains more than half its bulk of water, but, on compression by overlying sediment, part of the water is driven out, either upward, downward or sidewise. Evidently, vast quantities of water must so have been expelled from the enormous masses of rock that now underlie, for example, the Appalachian region, much of the rock at present having less than 1 per cent. of pore space. Furthermore, such water-bearing sediments, when carried down several thousand feet, must in higher temperature expand and drive out water in some direction, the water flowing much the more readily from its lessened viscosity at a higher temperature.

Moreover, the gradual deposition of mineral matter from the stationary film of water around the grains of a sandstone, and the consequent absorption of other mineral matter by the film from neighboring circulating water, and again the deposition of this absorbed material, until the rock becomes much more compact and less porous, must occasion the expulsion of great quantities of water in the case of vast bodies of rock. The consolidation of 50,000 square miles of sediment 1,000 feet deep, with an original pore space of 33 per cent. reduced to 3 per cent., must require the expulsion of a sheet of water 50,000 square miles in area and 300 feet deep, and its replacement by solid rock material—enough material to take the Mississippi River 60,000 years to supply, even with 150,000,000 tons carried in solution annually to the sea, according to T. M. Read's high estimate. Of course, such subterranean movements of the water must be extremely gradual and last through immensely long periods of time.

Some computations of the rate of flow of more superficial waters under definite conditions are given, and thereafter a comparison with results actually observed on a large scale in nature. For these computations the rate of flow is taken to be, according to Poiseuille's law, proportional to the pressure and inversely proportional to the length of the sand column; and proportional to the square of the diameter of the grains, in this respect nearly in agreement, too, with the 300 experiments on the ten grades of quartz sand. The computations show that at the drainage outlet of a bed of sand fully supplied with water and 10 feet thick, rising 1 foot in 10, the slope or gradient just compensating for the loss due to increase of length traversed by the water, a square foot of outlet surface would yield for the coarsest (2½ millimeters) sand about 5¼ cubic feet a minute; but for fine sand only a quarter of one ten-thousandth of a cubic foot, or, compared with the result for the coarsest sand, as one minute to 138 days; and for fine sandstone less than a hundred-thousandth of a cubic foot; showing that the rate of flow varies between very wide limits. In like manner the rate of flow is calculated for several supposed sands, and

with dips also of 1 in 1,000 and 1 in 2,000; and it is found that the results are far less than the yield actually found by Darton under comparable circumstances in the Dakota artesian basin. It is, therefore, clear that ground water in moving long distances must flow not merely through the pores, but in great part through joints and fissures, perhaps even through such passages in beds adjoining the water-bearing bed proper. Similar calculation of the theoretical rate of seepage into a portion of the Los Angeles River, into the flume of the West Los Angeles Water Company, and into the pipes of the Crystal Springs Land and Water Company, shows in each case results so much less than the ones really observed as to make it evident that the actual supplies of water must be accounted for otherwise than by mere seepage through capillary pores, and probably by larger submerged open waterways, even in the case of loose river sands. In the soil the passage of water is facilitated by worm burrows and the holes left by decayed rootlets.

In one experiment 200 cubic feet of water was forced in four days into a 7-inch well 13½ feet deep in undisturbed soil, where the ground water surface was 11⅝ feet below the top of the ground. The well was curbed with 5-inch unglazed drain tiles in 1-foot lengths. The water surface in the well was maintained at 7 inches below the top of the ground. Though the ground water surface was made to rise steeply within 2½ feet of the well, that surface at 4 feet from the well was raised only about 3 inches, showing that much of the 200 cubic feet of water must have spread away in all directions to quite long distances.

Experiments were made with a tank 14½ feet long by 4 feet deep and 1 foot wide, filled with mixed sand, and having a vertical drain tile inside one end to supply water, and four cross tiles at different points to drain off the water with cocks outside, and having fifteen pressure gauges uniformly distributed along one side. The water was discharged by one cock or another, and the pressure at the bottom of the tank at different distances from the outlet was noted, and was plotted in curves upon an elevation-drawing of the apparatus. The curves descend very gradually at the supply

end, and much more rapidly near the outlet. This illustrates what is observed on a large scale in nature.

For, contrary to widespread belief, the ground water surface near streams and lakes is higher than their water, and the movement is towards them, not from them. The contour of the ground water surface, as tested by numerous wells and shown in map illustrations, is found to conform somewhat to the shape of the surface of the ground, but deeper below it at higher points than in the valleys and with variations due to such circumstances as the varying porosity of the soil or the drainage of neighboring streams, wells, or tile drains. The ground water surface is far from level, and at one point has a gradient of 5 per cent. towards a lake only 150 feet distant; and at another point a gradient of 6 per cent. Plainly, then, streams, small lakes and low grounds receive throughout their course much, in fact, nearly all, of their water from adjacent higher land.

The amount of water, then, that has passed through the soil is enormous, as may be seen from estimates of the run-off. Newell has pointed out that the run-off in the region east of the Mississippi, except towards the northwestern corner, is about half the rainfall; in the region next west to the western edge of Missouri, it is about two-fifths of the rainfall; and in a narrow strip to the west of that, about three-tenths; and in a region still further west to the eastern part of Montana, it is from one-fifth to one-quarter. In the more level part of the United States, therefore, one-fifth to one-half of the rainfall goes into the streams; but, as we have seen, far the larger portion of that run-off has once penetrated the soil and emerged again before it reaches the river channels.

The tank afterwards had three more sets of gauges added, making sixty in all, and the water was drawn off by a cock near the middle of the bottom of the tank, while the sand was kept full of water to the surface. The pressures indicated by the gauges are shown in curves plotted upon a drawing, agreeing with Slichter's indication of the great decrease of pressure near a drainage outlet, even when the ground water surface remains undisturbed. But King con-

siders it very rare for such conditions to exist as to make that type of well interference at all marked, and that the serious cases of well interference come from an actual lowering of the ground water surface.

It was found by a trial of the interference of two wells 1,133 feet apart that pumping one did really change sensibly the level of the water in the other. This fact may appreciably affect some of the mathematical formulas; for in them the distance of 600 feet was taken to be the limit of such change to the ground water surface.

With the same tank experiments were also made that show the effect of adding a small quantity of water, corresponding in nature to the percolation of rainfall, to be very great in raising the ground water surface; because the empty space in the zone of soil nearly saturated by capillary attraction just above the level of the ground water surface is very small indeed, as appears also from King's experiments with five columns 8 feet long of sand of different coarseness left to dry even two years and a half. In all the five sands the lower foot was left very moist, and, in the two coarser ones, the next foot upwards was much drier, and above that there was little change; while the other sands were more uniformly drier from the bottom foot towards the top of the ground. The result is that a very small rainfall $\frac{1}{4}$ or $\frac{1}{8}$ of an inch in any of the sands would suffice to raise the ground water surface a foot; about 5 inches and less than 13, according to the coarseness, to raise it 4 feet. Of course, for short periods of drying, say a few days, the amount of rain required for the same results would be much less. As the ground water surface rises, then, more rapidly in soils of close texture, they would, with greater head, drain out more rapidly and contribute a large share to the swelling of the streams. Furthermore, observation shows that the ground water of low-lying land, from nearness to the surface, may, by rain, be raised to the highest level and begin to fall again before the rain water can percolate to the bottom of the deeper partially dried soil of the higher land.

Movement by capillary attraction takes place in all directions that lead from water-filled pore spaces of the soil to

others that are empty or only partly filled; and is quite rapid to a height of 4 feet, but its limit of height is not known. Its most general effect is to lessen the ground water by bringing it to the surface of the soil or to the roots of plants, and so to evaporation. The coarser the soil, the less the capillary attraction movement. The five columns 8 feet long of sand of different coarseness, after evaporation for two years and a half, still retained from $4\frac{1}{4}$ per cent. of water in the coarsest to nearly 12 per cent. in the finest. The water left was chiefly near the bottom of the column, where it varied only from $21\frac{1}{2}$ to 24 per cent. Other experiments showed that evaporation was very much the most rapid when the ground water surface was less than 18 inches from the surface of the ground, and greatly lessened with an increase of depth. Clearly, then, where the ground water surface is more than 8 feet deep, nearly the whole rainfall must descend at once too far for capillarity to bring it again to the surface. The percolation of the rainfall is hastened by worm burrows, holes left by decayed roots and by shrinkage cracks. It is hindered by the air that has filled the empty pore spaces, and that escapes with especial difficulty from the finer soils.

The natural movement of water in the ground is affected by barometric changes of the weather; and a lessened barometric pressure causes a more rapid discharge of water from springs, flowing wells, tile drains and seepage outlets of all kinds. The reason is not yet perfectly certain; but King suggests that it may be either because the general level of the ground water surface is bodily lowered or raised, just as in the case of portions of the surface of the open ocean, by the greater or less pressure of the atmosphere upon it; or because the partially confined air in the soil may drive out the water more or less strongly according to the lessened or increased resistance of the atmospheric pressure. (Is it not rather that the column of water, more or less perfectly closed above by the soil, somewhat difficultly permeated by the air, as just intimated, thereby practically resembles a barometer tube, and a lessening of atmospheric pressure upon the open drainage outlet allows

the water to issue more rapidly by its own weight?) Diurnal changes of temperature also hasten or retard the flow of water through the soil, not so much by changing the viscosity of the water as by the expansion or contraction of the gas confined in the soil with and above the water.

Serious and very costly mistakes in well digging are made from ignorance of the laws of the movement of ground water. The City Water Works Company, of Whitewater, Wis., was just about to ask for bids for a second well, for $1,200 or $1,500, when King suggested lowering the level of discharge of the first well, so as to increase the head of water pressing into the well. Thereby the capacity of the well was more than doubled, for it is to be borne in mind that the yield is directly proportional to the amount the water is lowered in the well, that is, to the head or pressure. A well at the dairy building of the University of Wisconsin was stopped on reaching a loose sand, and a building was erected above; so that the well could not be deepened without great expense, when it was found a large water supply was needed, such as could have been obtained by sinking deeper at first for an outlay of $60.

The flow, however, as shown by Slichter's calculations, does not increase exactly in proportion to the depth of penetration into the water-bearing bed; for the shallower wells have a larger supply from their bottom. But his calculations show that an increased depth of the water-bearing bed below the bottom of the well increases the yield only a little for the first few feet, and beyond that very slightly, and in all only $\frac{1}{8}$ up to a depth of 100 feet, and for greater depths insignificantly, and beyond 400 feet not at all. Besides, the beds are never perfectly homogeneous, and particularly not so vertically, and the water generally flows more readily along the bedding planes than across them. The flow towards a well, too, will be out of the finer grained layers into the coarser ones, in which, also, the reduction of pressure is greater and farther reaching. In casing a well, then, care must be taken not to let the end of the pipe stop in a fine-grained layer. The flow from the

finer grained beds with higher pressure and higher speed, or from local crevices, into the coarser beds is liable to carry along small particles of sediment that tend to settle in the slower moving streams of the coarser beds and clog their pore space and by degrees appreciably reduce the yield of the well.

The public is certainly much indebted to the authors and to the Survey for so thorough, careful and practically useful a discussion of the laws of the movements of ground water, applicable also in great measure to rock oil.

PHILADELPHIA, May 8, 1900.

CHEMICAL SECTION.

Stated Meeting, held Tuesday, November 21, 1899.

THE INFLUENCE OF SCIENCE IN MODERN BEER BREWING.

BY FRANCIS WYATT, PH.D.,
Member of the Institute.

(*Concluded from p. 214.*)

In order to prepare zymase, brewers' yeast is carefully mixed with an equal weight of quartz sand and infusorial earth, and rubbed down until the mass is soft and plastic. Water is added to this paste and the whole is placed in a pressing cloth and gradually subjected to a pressure of 400 to 500 atmospheres. The residual mass is again rubbed down, moistened with water, replaced in the pressing cloth, and subjected to the same pressure as before. In order to remove traces of turbidity, the total expressed fluid is mixed with a small quantity of infusorial earth and, after pouring over the first portion several times, is finally filtered through a paper filter. It now appears as a clear but opalescent yellow fluid with a pleasant odor of yeast. Its minimum specific gravity should be 1·0416. When boiled, there is a marked separation of coagulum, so that

the fluid almost stiffens. The formation of insoluble coagulum commences at about 95° F., preceded by the escape of the carbonic acid gas, with which the fluid is saturated. The extract should yield upwards of 10 per cent. of dry substance, and it should have the faculty of causing fermentation in saccharine solutions.

The investigations and discoveries of Buchner have proved the correctness of Liebig's suspicion, and justified the painstaking—if unsuccessful—labors of Traube, Claude-Bernard, Berthelot and many other equally prominent investigators who have believed in other than mere hydrolyzing enzymes like diastase. Now that zymase has really been found and isolated, however, it is a question whether we can make any practical use of it in the fermentation of beer, or whether it is to be regarded in the light of an interesting scientific discovery only.

I cannot, of course, presume off-hand to answer this question one way or the other; but, as I now see the matter, it would appear that the sole method of producing zymase is by extracting it from yeast by some modification or simplification of the process I have just outlined. I am, therefore, led to ask, whence are we to get the needed supply of yeast for its extraction, and what would be the compensating advantages which our brewers would derive from its use? We must not forget that yeast performs many functions in our worts during the course of fermentation besides the mere production of alcohol and carbonic acid gas. It removes certain objectionable bodies of the albuminous and resinous types, and thereby facilitates clarification and insures stability. Can these functions be performed by zymase? Then again, the production of yeast in a brewery is a matter involving great care and great cleanliness and great delicacy of treatment, but it is produced for comparatively nothing. If zymase can be obtained only from yeast, whence is the brewer to get his supplies and what is it going to cost him? What are its keeping qualities? How is it affected by the temperatures at which fermentations are conducted in this country? These are important questions, and there are a number of others of still greater importance

which will occur to those who give this interesting work of Buchner's the consideration it deserves.

Buchner demolished the pet theory of the majority of scientists by proving that the production of alcohol and carbonic acid gas from the fermentation of sugar is not the result of "life without air." Some of these days we may find out how this discovery is going to help us to make better beer.

The species of wild yeast most commonly found contaminating our beer worts are the *Saccharomyces pastorianus*, *Saccharomyces ellipsoideus*, *Saccharomyces exiguus* and *Saccharomyces apiculatus*. All these are present in the atmosphere as well as on the surface of all fruits and seeds, so that if a brewer's wort is freely exposed to the air, it will, in the course of a few hours, develop a spontaneous fermentation. These various species of wild yeast will be accompanied by various species of bacteria and moulds, which will rapidly grow and multiply, and in a few days—if left to itself—the wort becomes covered with a thin film, emits a disagreeable smell, and soon putrefies.

The species of bacteria or disease germs commonly met with in breweries are:

The *Bacillus subtilis*, *Bacillus amylobacter*, *Bacterium termo*, *Bacterium aceti*, *Bacterium lactis* and *sarcina*, and of these, we know that the *Bacterium aceti* has the power of converting the alcohol of the beer into acetic acid or vinegar; the *Bacterium lactis* attacks the saccharine matter, converting it into lactic acid, whilst butyric acid is derived from the further fermentation of the lactic acid by means of the Bacillus amylobacter.

The two well-known kinds of fermentation used in this country are known as "top" and "bottom." Top fermentation produces ale, and is carried on at temperatures between 55° and 75° F. The yeast is conveyed to the surface, and the fermentations generally last from four to seven days. Bottom fermentation produces lager beer, and lasts from nine to fourteen days. It takes place at temperatures between 2° R. and 9° R. The yeast, by reason of the sluggish nature of the fermentation and its heavier specific

gravity, subsides completely to the bottom of the fermenting vessel, although during the earlier stages the head exhibits the same appearance as the top fermentation.

Having thus dealt with the materials used in the modern brewery, I will now give a brief descriptive outline of the modern brewing plant, which is nearly always so arranged that everything may run by gravity, thus avoiding unnecessary pumping.

(1) Hot and cold water tanks, with all necessary connections.

(2) The "Raw Grain Masher" or decoction tub, which is a large, round, iron vessel, provided with a jacket, for either steam or cold water, and with an inside connection for introducing live steam into the mash. Its internal rakes are adjusted so as to sweep as closely as possible the sides and bottom, and it has a sparger for hot or cold water, the necessary steam and water gauges, and thermometers being affixed externally. It is generally large enough for the treatment of 300 bushels of grist, and it always commands the malt mash-tub from an elevation of about 6 feet, being connected with it by a 6-inch pipe.

(3) The "Malt Mash-Tub" is a vessel built of sheet steel and provided with a copper false bottom. It has strong revolving rakes, and a scraper which may be lowered to within $\frac{1}{8}$ inch of the bottom or entirely raised from the mash by means of a hydraulic hand pump.

(4) A steam-jacketed copper boiling kettle, in which the whole of the worts collected from the mash-tub are boiled with the hops.

(5) A hop-jack to receive the finished worts when they run from the kettle.

(6) Several good pumps for wort, beer or water.

(7) A sheet-iron open surface cooler, provided with a fine spraying apparatus, through which the wort is pumped from the hop-jack.

(8) A Baudelot refrigerator, the upper coils of which are cooled with cold water, and the lower ones with cold brine or by direct expansion of ammonia.

(9) An ice machine and all accessories for the production

of cold. Imagine a compressor driven by a steam engine. This compressor receives ammonia in the form of vapor from the other end of the system and compresses it, heating it, of course, at the same time. The compressed ammonia passes into a condenser, or coil of pipes, on the outside of which trickles a stream of cold water, which carries off the heat from the ammonia and thus causes it to liquefy. The liquid ammonia goes into a separator and settles to the bottom. The opening of a certain valve of special construction allows this liquid ammonia to expand and escape into coils of pipe. In the act of expansion it absorbs heat and the surroundings are thus cooled. Having reassumed the form of vapor, it is now led back to the compressor and again liquefied.

(10) Boilers, engines, elevators, malt bins, malt screens, malt mills, and scales. A cold storage room for the hops, well insulated, is connected with the refrigerating machine.

(11) Well-insulated and cooled fermenting rooms and cold storage rooms, all so arranged by connection with the refrigerating plant as to facilitate the maintenance of any desired temperature, from the freezing point up to 55° or 60° F.

(12) Fermenting tubs, storage casks, and finishing or pressure casks, all varnished on the inside with the best insoluble, hard, elastic shellac varnish; filters, racking apparatus and trade barrels of all the various capacities to meet requirements.

It is perhaps hardly necessary for me to tell you that science has impressed upon the modern brewer the condition *sine qua non* of absolute cleanliness as the principal factor in the production of good beer. Let him neglect this condition and he can no more make good beer than water can run up hill. Before commencing his work, therefore, he will always see to it that his plant is perfectly clean; that the false bottom of his mash-tub is properly adjusted, and that none of the holes are clogged up. He will also see that the raking gear moves with perfect freedom and ease; and that it is adjusted to any necessary speed to make a mash of proper consistency. He will test the thermometers,

and see that they record correct temperatures, and will try all the valves and taps.

Proceeding by progressive steps, he has also been brought to realize that next in importance to cleanliness comes the question of the different temperatures which are to be observed throughout the various phases of his brewing process, and, as this is the very *crux* of my present exposition, I will try to make it more clear to you by a glance at what actually should take place when the malt is mixed in the mash-tub with the water at correct temperatures.

(1) The pre-formed sugars of the malt, together with the soluble albuminoids or nitrogenous bodies and the mineral salts, go into solution.

(2) The starch of the malt is gelatinized by the hot water.

(3) The diastase acts upon the starch in strict accordance with the temperatures to which it is exposed.

You will perceive from this that the conversion products may be varied at will, and the production of any desired type of beer be positively assured.

If, for example, we employ low temperatures for the preliminary digestion of the malt in order to accomplish Phase No. 1, and then raise the temperature either by means of steam or additional hot water to, say, 148° F. to accomplish Phases 2 and 3, we know that we shall be effecting our conversion under the optimum conditions favorable to the action of the diastase. Our worts will, therefore, contain a large proportion of free and directly fermentable maltose sugar, which, by fermentation, will produce a very alcoholic, or, as it is technically termed, a very vinous beer.

If, on the other hand, we rise rapidly from the low temperature of digestion to 154° or 156° F. in order to accomplish Phases 2 and 3, we shall so restrict the action of the diastase, so cripple it, in fact, that our worts will contain a comparatively small proportion of free maltose and a correspondingly large proportion of malto-dextrine and dextrine; and our fermented beer will have comparatively little alcohol and much "body" or residual unfermented extract.

Thus, you see, science has found out and demonstrated

that the type of beer desired may always be obtained by a proper regulation of temperatures, and I shall endeavor to give you an example of this by a brief description of the brewing process proper, conducted in accordance with modern views. Let us suppose that we require 200 barrels of a beer of vinous character. We establish the initial temperature of the mixture of malt and water at 137° F., in order to thoroughly digest the grain and dissolve out all the diastase and other soluble nitrogenous bodies. We next accomplish Phase 2 and Phase 3 of the process at 148° F., in order to facilitate the action of the diastase and to thereby produce a ratio of fermentable to non-fermentable matter in the wort which shall be in the neighborhood of 1 : 0·37. We finally raise the temperature of the mash to 155° F. to prevent undue cooling off and the consequent formation of excessive acidity.

We wash out or exhaust our grains with water at 160° F. in order to maintain the temperature of the mash at about 154° F. throughout the operation, despite losses by radiation.

The water is run into the mash-tub in the proportion of 1·75 to 1 (by weight) of the grist, and at a temperature of 154° F. The mashing machinery is now started to revolve at moderate speed; the malt hopper is opened and 327 bushels of malt are run down into the water at the rate of 100 bushels in five minutes. When it is all down the mashing is continued for five minutes, and then the rakes are stopped and the mash rests for thirty minutes. At the end of this time sixteen barrels of boiling water from the hot-water tank are let into the mash as rapidly as possible from underneath.

This will give a temperature of 148° F., at which the gelatinization and actual conversion of the starch take place, and by which the type of the wort is established. After being maintained with constant mashing for twenty minutes, this temperature is increased to 155° F., for the purpose of keeping up the heat while the mash rests, or settles to form a filter bed over the false bottom of the tub.

When the mash has rested one hour the taps of the tub are opened full and allowed to run for about one-half

minute at their full capacity, in order to clear out the pipes. They are then adjusted so as to deliver about sixty or seventy barrels of liquid per hour.

When about ten barrels have run off into the wort kettle, the liquid running from the taps should have a temperature of about 153° F.

When thirty barrels of wort are in the kettle, the sparger on top of the mash-tub is opened, and twenty barrels of water are sprinkled over the grains. Thenceforward for every twenty barrels that run off from the mash-tub twenty barrels are put on top of the grains through the sprinkler until the soluble matter contained in them is entirely washed out.

Speaking in a general way, it is found that the required amount of total water to be used is in the proportion of 6 to 1 of grist. In the present illustration, therefore, since we intend to produce 200 barrels of wort in the fermenting tubs, we should have:

$$\text{Grist, } 11{,}128 \times \frac{6\cdot4}{259} = 275 \text{ barrels.}$$

Water used for first mash	75	barrels.
Water used in second mash, underneath, boiling	16	"
Water used in third mash, " "	14	"
	105	"

Water available for washing out the grains, 170 barrels.

The specific gravity of the last runnings into the kettle from the mash-tub in good practice is generally about 1·005.

The total quantity of wort run off into the kettle from the mash-tub is about 16 per cent. less than the total quantity of water used in the brew; the balance being mechanically absorbed by the grains.

The wort in the kettle is kept near to the boiling point, but not allowed to quite boil, until it is all collected, when it is boiled very steadily for two and one-half hours.

The hops are added as follows:

One-third when the kettle has been boiling thirty minutes.

One-third when the kettle has been boiling one and one-half hours.

One-third about twenty minutes before "turning out."

The quantity of wort discharged from the kettle at the boiling point is about 210 barrels, or in other words, is about 5 per cent. greater than what is required in the fermenting cellar at the necessary cold temperature.

If the wort produced in this manner is subjected to analysis, it will be found to exhibit the following average composition:

Specific gravity at 60° F.	1·053
Total solid extract (by weight), per cent.	13·37
Fermentable sugars in extract (estimated by Fehling's solution as maltose)	9·75
Proteids or nitrogenous matters (suitable as yeast food)	0·74
Total acidity (estimated as lactic acid)	0·14
Ratio of fermentable matter to the other bodies in the extract not fermentable	1:0·37
Ash (phosphates, etc.)	0·22

I will only pause to draw special attention to the amount of fermentable sugars in the wort, and the ratio in which they stand to the non-fermentable bodies, in order that you may form intelligent conclusions later on; and with your permission will now pass on to a consideration of another mashing operation, in order that its results may furnish material for proper comparison.

In the present instance we shall proceed with the mashing process on exactly similar lines, so far as the mechanical arrangements are concerned, but we shall replace a certain proportion of our malt by a certain quantity of raw grain. For the sake of brevity, let me tabulate the brew like this:

Quantity of wort required in fermenters	200 barrels.
Gravity of wort in fermenters, when cold	1·053
Ratio of fermentables to non-fermentables	1:0·51
Conversion temperature is to be	158° F.
Proportion of total water to grist is	6¾ to 1
The water for the malt mash is at	120° F.
Proportion of water to malt for the malt mash is	2·50 to 1
The raw grain mash is to be boiled	212° F.
The raw grain is mixed with 50 per cent. of its weight of malt.	
The proportion of water to the total grist in the raw grain mash is	2·50 to 1
Temperature of the water in the hot-water tank, to be used in the underflow of the mash-tub to bring up the tem-	

perature of the entire mash to the desired point at which it is to rest, is . . . . 212° F.
The final resting temperature of the mash . . . . 164° F.
The total amount of sparge water is of the total water to be used . . . . 58 per cent.
The temperature of the sparge water is . . . . 166° F.
The tap heat throughout the run is . . . . 158° F.

The hops used in the brew are in the same proportion as for the one preceding, and are used in the same manner.

In the first example we used 327 bushels of malt; in the present one we shall use:

213 bushels malt; 3,322 pounds corn grits (equal to 114 bushels malt); 276 barrels water.

The raw grain mash is made thus:

Corn grits	3,322 pounds.
Malt	1,661 "
Total	4,983 "

$$4{,}983 \times \frac{2\cdot50}{259} = \text{say, 49 barrels of water.}$$

The forty-nine barrels of water are in the raw grain tub or converter at a temperature of 130° F. The rakes are started and the malt is put in first; then follows the corn; then the steam is turned on, and the temperature is raised 1° F. per minute until it boils. Boiling is continued for one hour, and the boiling mass is then run into the malt mash-tub below. When the converter is empty, it is washed out with seven barrels of water. Allowing five barrels for evaporation, this makes a total of fifty-one barrels of water in the raw grain mash.

The mashing of the malt is done thus:

Malt, 5,572 pounds.

$$5{,}572 \times \frac{2\cdot50}{259} = 54 \text{ barrels of water.}$$

The fifty-four barrels of water are in the mash-tub at 120° F. The rakes are set in motion when the corn mash has been boiling for thirty minutes, and the malt is let down at moderate speed and mashed slowly. As soon as the raw grain is ready, the two mashes are brought together

as quickly as possible, and kept in motion for thirty minutes, the temperature being as follows:

Foundation temperature of malt mash water	120° F.
Initial temperature of malt and water mixed	109° F.
Conversion temperature of the combined raw grain and malt mashes	158° F.

At the end of the thirty minutes the temperature of the mash is raised to 164° F. by means of fifteen barrels of boiling water, which are let in through the false bottom as quickly as possible. The rakes of the mash machine are stopped and the mash is allowed to rest for one hour in the usual way.

I need not again describe the balance of the operations of running off the wort and sparging, because they are conducted exactly as in my first example; the quantity of sparge water is the balance between the total water required for the brewing, calculated at 6¾ to 1, by weight, of the total grist, and the water already used as I have set forth.

If, after boiling, hopping and cooling this wort, we subject it, like the other, to chemical analysis, we shall find that its composition is as follows:

Specific gravity at 60° F.	1·053
Total solid extract (per cent.)	13·37
Fermentable sugar in extract (estimated by Fehling's solution as maltose)	8·80
Proteids or nitrogenous matters (suitable as yeast food) . .	0·53
Total acidity (estimated as lactic acid)	0·12
Ratio of fermentable matter to the other bodies in extract not fermentable	1 : 0·52
Ash (phosphates, etc.)	0·19

I do not think you can fail to at once perceive the difference in the amount of fermentable sugar, and the ratio in which it stands to the non-fermentable bodies, as compared with the wort from our first brew, but in any event I again impress it upon your attention for future reference.

The wort that has been boiled in the kettle as I have described has to be cooled and mixed with the yeast. To this end, the valve of the discharging pipe of the kettle is opened wide and the boiling wort is allowed to run by

gravity into the hop-jack. This hop-jack is provided with good false bottom plates to retain the hops, which form a filter bed for the wort, and prevent the passage of coagulated albuminoids and any other suspended matter. When the wort has settled in the hop-jack for thirty minutes the outlet valve is opened and the wort is pumped to the surface cooler or collecting tank, situated at the top of the brewery.

The chief objects to be effected at this stage of the operations are two in number:

(1) That of cooling; and

(2) That of oxidation.

In order that this all-important oxidation may effectually take place, it is necessary that the wort should be at a temperature very little below the boiling point. In about thirty minutes from the time it leaves the hop-jack the wort is conducted over coils of refrigerating pipes, the upper ones being cooled with cold water, and the lower ones either with cold brine or with ammonia directly expanded from the ice machine. The temperature of the flowing wort is continuously recorded in the pan of the refrigerator, which is sufficiently deep to allow a considerable quantity to accumulate, and must be carefully maintained at the desired point.

No chemical change takes place in the wort while it is passing over the refrigerator, but it absorbs a certain amount of free oxygen mechanically, which the yeast uses up before commencing its attack upon the sugars. The mixture of the yeast takes place in the starting tub as soon as the wort has reached the proper temperature.

The fermentation, storage and finishing of the beers take place either in vast cellars underneath the brewing rooms or in a cold storage house immediately adjoining them. In the best modern establishments the fermenting room is situated at the top of the building, and the beers run through the various subsequent processes by natural gravity. Each department is well ventilated, the floors are paved with cement or asphalt, and the walls and ceilings are cemented and enamelled and kept perfectly dry. The

cooling pipes connected with the ice machine are suspended from the ceiling or hung upon the side walls, well removed from the open fermenting tuns, and every precaution is taken to prevent any drips from falling into and contaminating the beers. The drains are well trapped and of large capacity, and plenty of use is made of cold water for flushing the floors, and of such disinfectants as chloride of lime, sulphate of iron, etc. The temperature of the fermenting room is kept at 40° to 42° F. The fermenting tuns are round vessels, built of oak; fitted with attemperators; varnished inside; capable of holding from 50 to 100 barrels, and provided with a manhole to facilitate proper cleaning and the withdrawal of the yeast. In a few breweries which are completely under the direction of trained scientists the beers are fermented with pure yeast, successfully cultivated from a single selected cell on the Hansen plan. In the majority of cases, however, it is still customary to constantly use the same stock, collected from the fermenting tubs. The yeast crop secured is generally three or four to one, and directly it is taken out it is washed with boiled cold water to free it from dirt and light yeast, allowed to settle, placed in a very clean tub, covered with boiled cold water, and stored away in the coldest possible condition. Beer enters upon its initial stage of fermentation in twenty-four to thirty-six hours from the time of adding the yeast, and its temperature will now rise at the approximate rate of a degree Fahrenheit every twelve hours. It usually reaches a maximum of 51° F. to 52° F., and the top, or cap—until then kept up by the evolution of carbonic acid gas—commences to fall back, and is skimmed off. The attemperating coils in the fermenting tuns are now put to work very carefully, and the temperature is reduced to 37° F. at the rate of about $\frac{3}{4}$° F. per twelve hours. The specific gravity of the beer is now about 1·015, and if it preserves this without change for twenty-four hours, and presents, after final skimming, a perfectly black appearance when regarded from above, its fermentation is at an end and it is ready to be sent off into the storage cellar.

The temperature of the storage cellar is kept as uni-

formly as possible at about 35° or 36° F., the storage casks being of oak, painted inside with a good coating of pitch, and of about 400 barrels capacity. In order that the quality, odor and flavor of the beers may be homogeneous and their specific gravity more regular, different brewings are distributed and mixed together throughout a series of casks, which are all fitted with porous bungs. No fermentation should take place in the storage room, but the beers must deposit nearly all suspended yeast, and become comparatively bright and ready to run down into the "chip cask" cellar in from twenty-five to thirty days.

In the chip cask cellar the beers are finished off for consumption, and it is kept at a temperature of about 40° to 41° F., the casks themselves having a capacity of from 50 to 100 barrels. The chip casks are coated inside with pitch, and their bottoms are strewn with a good layer of clean cedar chips, which are changed and carefully washed each time the casks are emptied. These chips (which give their name to the casks) are added in order to provide surfaces of attraction for the deposition of the yeast. The casks are filled by first introducing mature beer from the storage cellar to about half their capacity; then putting in about 12 or 15 per cent. of fresh young beer (thirty-six hours old), and then topping up with storage cellar beer. The specific gravity of the total cask contents is thus brought up to about 1·021, and after adding a small quantity of finings made from isinglass, the casks are closed and an automatic bunging apparatus is adjusted and regulated at a pressure of about 6 pounds per square inch. The beer now commences to undergo a second and final fermentation, and impregnates itself with carbonic acid gas under pressure. In about fourteen days, when it is ready for racking, it is run off through a filter into the trade packages, and is then immediately sent out for consumption.

When beers are intended for export they are invariably pasteurized. After being racked off and bottled, they are placed in a water-bath, gradually heated to a temperature of 152° F., held there for thirty minutes, in order to paralyze all living organisms, and then as gradually cooled down to

the normal temperature. They thus remain sound and perfectly brilliant for a very long period, and may be safely exported to hot climates, without deterioration or change.

As it was not my purpose at the outset to enter into explanatory details of mere practical processes of brewing, which can only interest those who are engaged in the art, and as my only object is to show you in what unlimited measure the march of science has influenced the development of modern beer brewing, I may turn away from any further consideration of the methods by which beers are actually produced and proceed to a more critical examination of the two beers which we have made here this evening, and of which I deeply regret my inability to produce material samples for your criticisms.

Referring to the tabulated results of the two worts, you will please remember that No. 1 was made from malt and hops only, while No. 2 was made from a mixture of malt and corn grits and hops. You will, therefore, be interested to study the analyses of the finished beers from these two brews, as sent out for consumption by the public:

	No. 1.	No. 2.
Original specific gravity	1·053	1·053
Specific gravity of finished beer	1·013	1·017
Carbonic acid gas	0·35	0·37
Absolute alcohol (by weight)	4·20	3·49
Volatile acidity (as acetic acid)	0·003	0·002
Total residual unfermented solids	4·67	6·39
Unfermented sugar in total solids	1·35	1·80
Total fixed acidity (estimated as lactic acid)	0·14	0·13
Proteids or nitrogenous matter	0·53	0·38
Ratio of sugars to non-sugars in total unfermented solids	1:2 50	1:2·55
Ash	0·20	0·19
Degree of fermentation	64 p. c.	54 p. c.

It is, of course, a very difficult matter for the uninitiated to grasp all the significance of these figures, but I am vain enough to hope you will be able to agree with me in the following interpretation of them:

(1) The character of the actual component parts of both beers, made in the one case from malt and hops only, and in

the other from a mixture of malt and raw grain and hops, is identical.

(2) The differences in their composition or in the arrangement of their components are only those which we knowingly created, first, by restricting the action of the diastase, and thus producing less fermentable matter in the wort, and less alcohol in the finished beer; and, second, by decreasing the amount of soluble proteids, and thus diminishing the liability of the beer to subsequent fermentative changes.

Do not these analyses make it clear to you, when taken with all the other things I have laid before you, that the modern scientific brewer should have a sufficient knowledge of his art to change at will the nature of his beers? Does it not appear to you that he can foretell with sufficient accuracy what result he is going to obtain from the use of any process he may deem it advisable to adopt, in order to fulfil any reasonable demand made upon him by a variation in public taste? What has he to do in order to produce beers that will be satisfactory from all points of view? He must see to it that his worts contain:

(1) The proper proportion of readily fermentable sugars.

(2) Certain other sugars and non-sugars which do not so readily ferment, but which are included in the "unfermented extract" of beer, and contribute to "roundness" or "mellowness."

(3) Free dextrine, which is quite unfermentable by the true beer yeast, and constitutes the bulk of the unfermented extract.

(4) A certain amount of free acidity, which I have estimated in my selected analyses as lactic acid, for the sake of convenience, but which really is largely made up of acid phosphates.

(5) The proper proportion of saline matters derived from the water, the malt and the hops, and mainly composed of phosphates, sulphates and chlorides of calcium and potassium, all of which are necessary as yeast food, and some of which contribute to the permanent solubility of the nitrogenous or albuminous matter of malt.

(6) The proper proportion of the nitrogenous bodies themselves, mainly made up of albumoses, peptones and amides.

The modern brewer knows, because science has taught him, that the main portion of the soluble nitrogenous bodies in malt serve as food for the yeast; and, as you yourselves can see by comparing my analyses of worts with those of the finished beers, they are partially eliminated by the yeast during the fermentation. Those which are not so eliminated impart nourishing qualities to the beer, and give it a round, full-mouthed taste and good foaming capacity. One of the great sources of trouble with them has ever been that their solubility, especially those of the albumose and peptone types, is constantly being affected by the chemical and physical changes undergone by the wort during the progress of its fermentation. Thus, for example, some of them fall out of solution as soon as alcohol commences to be formed, and the degree of their insolubility is coincident with the increase of the alcohol. Others, while perfectly soluble at normal temperatures—say, for example, at 50° F.—become insoluble as the temperature is lowered. For every downward variation in temperature a succession of them is precipitated, until the maximum is reached at or about the freezing point of water.

We may take a beer that is perfectly brilliant at 50° F., and find that upon being cooled to 40° F. it will become cloudy. If, after filtration, it is again cooled down to, say, 35° F., a fresh cloudiness will manifest itself; and so we may go on filtering and cooling for every successive drop in temperature, until the final precipitation point is reached.

In times gone by, when science was a myth, beers were kept in cold storage for many months, because when they were not so kept they readily became cloudy when sent out from the brewery, if they were placed on ice. The ice machine had not been invented; the cellars were imperfectly cooled by the use of natural ice, and the beers had to cool down spontaneously in the big storage casks. The mere fact that modern chemical invention now enables us, at the end of the primary fermentation of the beers, to rapidly re-

duce their temperature down to any required point by passing them through efficient coolers, and thus to immediately precipitate such forms of nitrogenous matter as are removable by cold, does away with the *necessity for prolonged cold storage*, and this of itself would have marked one of the most important steps in the advancement of brewing.

And now, ladies and gentlemen, if I have not tired you with unnecessary scientific details, and have made my attempted exposition partially clear and intelligible, you must have gained the conviction that chemistry and science generally have indeed done their share in promoting the advancement of this important branch of the industries of fermentation. I have already given you some statistics and bothered you with a great many figures, but I feel compelled to further trespass upon your indulgence in order to cite a few more.

According to the figures which I have gathered from official sources, the total production and sale of malt liquor in the United States in the year 1863 was 2,600,000 barrels; and, from my careful inquiry into the progress made in subsequent years, I find figures that are well-nigh incredible.

In 1868 the sales amounted to	6,147,000	barrels.
" 1873 " " " "	9,634,000	"
" 1878 " " " "	10,242,000	"
" 1883 " " " "	13,500,000	"
" 1888 " " " "	24,600,000	"
" 1893 " " " "	33,800,000	"
" 1898 " " " "	37,500,000	"

If I am creditably informed—as I believe I am—the cash capital actually invested in the brewing industry in this country now exceeds the sum of $250,000,000. The yearly value of the product made and sold is very approximately $225,000,000. The revenue collected from the brewers by the United States Government is closely in the neighborhood of $70,000,000 per year.

These are formidable figures, and I find in them ample justification for my preliminary statement of the benefits which have accrued to this industry from its alliance with science. To claim that chemical science has worked all

these wonders by itself would be, of course, unfair; and it is far from my desire to deprecate the contributions of mechanical engineering.

At the present time the interests of science and of practice are regarded as identical, but they have not always been so considered. It is not so many years ago that purely practical brewers and "masters of the mysteries" were prone to scoff at the theories of what they called "the beer doctor;" but the march of technical education has naturally reacted in the chemists' favor; and it is a fact which I am proud to place on record, that there is no more welcome or honored guest in the brewery of to-day than the chemist and biologist. If the theories that are worked out in the laboratory are at first regarded with doubt and suspicion, they are eventually put to the test in the brewery on the industrial scale; and as they thus carry conviction, every advance in scientific discovery is accompanied by a corresponding movement in the industry whose welfare we are working to promote. On the other hand, it is quite obvious that with every step forward that is taken by the practical industry itself, fresh fields for investigation are opened up for the scientist; and thus the growth of the science and the industry are made dependent upon each other; and they must consequently be ever wedded and pass on happily, in the paths of progress, hand in hand.

RECAPITULATION OF IMPORTANT DATA EMBODIED IN THIS PAPER.

COMPARATIVE TABLE OF THE COMPOSITION OF THE CEREALS USED BY MODERN BREWERS IN THE BREWING OF MODERN BEERS.

	Malt.	Corn Grits.	Rice.	Barley.
Moisture	4·00	10·50	10·60	12·00
Starch, sugar and gum	68·00	76·40	81·00	60·00
Fat	2·25	0·65	0·10	2·50
Nitrogenous matters (soluble)	4·00	0·00	0·00	0·00
Nitrogenous matters (insoluble)	8·00	11·00	7·20	12·00
Mineral matters	2·25	0·45	0·90	2·50
Cellulose or husk	11·50	1·00	0·20	11·00

NECESSARY DETERMINATIONS TO BE MADE BY CHEMISTS IN THE ANALYSIS OF BREWING WATER.

(1) Hardness before boiling.

(2) Hardness after boiling.

(3) Total solid residue after evaporation.
(4) Residue after calcining the above at low red heat.
(5) Bases and acids.
(6) Free ammonia.
(7) Albuminoid or organic ammonia.
(8) Oxygen required to oxidize the organic matter in five minutes at 80° F.
(9) Oxygen required to oxidize the organic matter in 3 hours at 80° F.
(10) Nitrous acid or nitrites.
(11) Nitric acid or nitrates.

Substances Entering into the Composition of Brewers' Wort.

Maltose.
Malto-Dextrines.
Dextrines.
Albuminoids or Proteids.
Mineral Salts.

Table Showing the Amount of Malt Adjuncts that will Yield as Much Extract in the Mash-Tub as One Bushel of Malt.

Twenty-seven and one-half pounds flaked corn.
Twenty-six and one-half pounds rice.
Twenty-six and one-half pounds grape sugar or glucose.
Twenty-nine pounds corn grits.

Table Showing the Diminishing Influence of Heat upon Diastase During the Kilning of Malt.

Temperature.	Moisture.	Diastasic Power.
140° F.	7·00	168
150° F.	5·00	145
160° F.	4·20	120
175° F.	3·10	105
190° F.	2·05	87

Complete Tabulation of a Brewing in Which the Wort is Brewed from a Mixture of Malt and Raw Grain and Hops and is to Produce a "Full-Bodied," Non-Vinous Beer.

Quantity of wort required in fermenters	200 barrels.
Gravity of wort in fermenters, when cold	1·053
Ratio of fermentables to non-fermentables	1:0·51
Conversion temperature is to be	158° F.
Proportion of total water to grist is	6¾ to 1
The water for the malt mash is at	120° F.
Proportion of water to malt for the malt mash is	2·50 to 1
The raw grain mash is to be boiled	212° F.
The raw grain is mixed with 50 per cent. of its weight of malt.	
The proportion of water to the total grist in the raw grain mash is	2·50 to 1

Temperature of the water in the hot-water tank, to be used in the underflow of the mash-tub to bring up the temperature of the entire mash to the desired point at which it is to rest, is	212° F.
The final resting temperature of the mash	164° F.
The total amount of sparge water is of the total water to be used	58 per cent.
The temperature of the sparge water is	1166° F.
The tap heat throughout the run is	158° F.

Composition of a Wort Brewed from Malt and Hops Only and Destined to Produce a Vinous Beer (No. 1).

Specific gravity at 60° F.	1·053
Total solid extract (by weight), per cent.	13·37
Fermentable sugars in extract (estimated by Fehling's solution as maltose)	9·75
Proteids or nitrogenous matters (suitable as yeast food)	0·74
Total acidity (estimated as lactic acid)	0·14
Ratio of fermentable matter to the other bodies in the extract not fermentable	1:0·37
Ash (phosphates, etc.)	0·22

Composition of a Wort Brewed from Malt, Raw Grain and Hops, Destined to Produce a "Full-Bodied," Non-Vinous Beer (No. 2).

Specific gravity at 60° F.	1·053
Total solid extract (per cent.)	13·37
Fermentable sugar in extract (estimated by Fehling's solution as maltose)	8·80
Proteids or nitrogenous matters (suitable as yeast food)	0·53
Total acidity (estimated as lactic acid)	0·12
Ratio of fermentable matter to the other bodies in extract not fermentable	1 : 0·52
Ash (phosphates, etc.)	0·19

Table of Comparison Between the Finished Beers Resulting from the Fermentation of Wort No. 1, Made from Malt and Hops Only, and Wort No. 2, Made from Malt, Raw Grain and Hops.

	No. 1.	No. 2.
Original specific gravity	1·053	1·053
Specific gravity of finished beer	1·013	1·017
Carbonic acid gas	0·35	0·37
Absolute alcohol (by weight)	4·20	3·49
Volatile acidity (as acetic acid)	0·003	0·002
Total residual unfermented solids	4·67	6·39
Unfermented sugar in total solids	1·35	1·80
Total fixed acidity (estimated as lactic acid)	0·14	0·13

Proteids or nitrogenous matter	0·53	0·38
Ratio of sugars to non-sugars in total unfermented solids	1 : 2·50	1 : 2·55
Ash	0·20	0·19
Degree of fermentation	64 p.c.	54 p.c.

TABLE SHOWING THE INCREASE IN THE PRODUCTION OF MALT LIQUORS IN THE UNITED STATES, FROM THE YEAR 1863 TO 1898.

In 1868 the sales amounted to	6,147,000 barrels.
In 1873 " " " "	9,634,000 "
In 1878 " " " "	10,242,000 "
In 1883 " " " "	13,500,000 "
In 1888 " " " "	24,600,000 "
In 1893 " " " "	33,800,000 "
In 1898 " " " "	37,500,000 "

Franklin Institute.

[*Proceedings of the stated meeting held Wednesday, September 19, 1900.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 19, 1900.

Vice-President THEO. D. RAND in the chair.

Present, 128 members and visitors.

Additions to membership since last report, 22.

The Secretary read a letter from President Birkinbine, expressing his regret at not being able to be present at the opening meeting of the season, and calling attention to the need of active co-operation on the part of the members in behalf of the Endowment Fund of the Institute and for the increase of the membership.

The presiding officer introduced Mr. Fred. W. Unger, of Philadelphia, who had recently returned from the scene of the war in South Africa, where he had been engaged as war correspondent for several prominent English journals. Mr. Unger gave an interesting description of the military operations of the Boer-British conflict, dwelling specially on the engineering features of the subject.

Prof. Arthur J. Rowland, Drexel Institute, Philadelphia, presented a paper entitled "Mistakes in the Rating of Incandescent Electric Lamps," in which he gave the results of his investigations respecting the useful light-emitting efficiency of the different types of incandescent lamps. The paper was discussed by Dr. Geo. F. Stradling, Mr. W. C. L. Eglin, Dr. Francis Head, and the author. (Paper and discussion will be found in this impression of the *Journal.*)

Mr. W. N. Jennings exhibited and commented on several lightning photographs which he had taken, and the meeting was adjourned.

WM. H. WAHL, *Secretary.*

JOURNAL

OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CL, No. 5. 75TH YEAR. NOVEMBER, 1900

IMPROVEMENTS IN BRIDGE CONSTRUCTION.

[*Being the report of the Franklin Institute, through its Committee on Science and the Arts, on the Exhibit of the Pencoyd Iron Works, at the National Export Exposition, held in Philadelphia, October–November, 1899. Sub-Committee.—Thos. P. Conard, Chairman; J. Y. McConnell, Jos. Hartshorne, H. F. J. Porter, H. V. Wille, Paul Kreuzpointner, Walter Cramp, Harrison Souder.*]

HALL OF THE FRANKLIN INSTITUTE,
[No. 2106.] PHILADELPHIA, March 28, 1900.

The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the exhibit of the Pencoyd Iron Works at the late National Export Exposition, 1899, which was referred to it by the Bureau of Awards of the said Exposition, reports as follows:

The exhibit consisted of a very creditable and interesting display of steel structural shapes, girders, bridge materials, etc., and a full-size model of one of the expansion ends of the Delaware River Bridge, with its roller bearings.

Apart from the high quality of the articles exhibited, and the exceedingly interesting display made, the attention of your sub-committee was called to some special features in the construction and erection of several important bridges recently built by the company, namely, the Niagara and Clifton Bridge, at Niagara Falls, the Atbara River Bridge, over the Atbara River, for the British Government, and the Delaware River Bridge of the Pennsylvania Railroad Company, near Philadelphia, descriptions and blue prints of which were submitted by the company, and are on file with this report.

In the case of the Niagara Bridge the conditions were very difficult and exacting; first, the center or main span over the river is of unusual length (more than 200 feet longer than any arch structure ever before attempted), and second, the great depth of the river and the rapidity of the current rendered false-works entirely impracticable.

The pattern determined upon was that known as a two-hinged arch, consisting of two complete arch trusses resting on heavy cast-steel abutments, built into the solid rock at each side of the river, and rising to a height of 150 feet at the center. These are held together by lateral bracings in the usual manner, and the roadway is carried by vertical posts rising to the level of the tops of the arches.

The most interesting features in this case are the method adopted by the designer for closing up the arches at the center and the accuracy with which his plans were carried out.

Owing to the absence of false-works, it was of course necessary to build out the structure from either side of the river simultaneously on the cantilever system, until they should meet in midstream. To sustain the great weight of the arches during construction, heavy anchorages were built on both sides of the river, from which lines of eye-bars were carried over the approaches and attached to the upper chord. These were removed when the bridge was completed.

In all structures of this sort economy of material is a matter of the greatest importance, not only on account of

expense, but for the purpose of reducing the dead weight to be carried. To this end the most careful calculations are made to ascertain the minimum weight of materials required to carry the prescribed load added to the weight of the structure itself, and at the same time provide an ample factor of safety. The strains to which every member of the structure will be subjected are carefully figured out, and the section and weight required determined accordingly. The ultimate strength of the whole structure depends, therefore, on the accuracy with which every part is made to carry its calculated strains. To secure the perfect adjustment of the strains in the arches of the Niagara Bridge was the object of the method of "closing up" adopted.

The method was as follows, quoting from a paper submitted by the company:

"The deflections were carefully figured and the toggles for the final adjustment set so that, according to figures, the lower center panel point ought to have come exact at the normal temperature. It was then expected to close up at this lower panel point with a pin, so that after the anchorage was removed the structure carried itself as a three-hinged arch. In this condition the two upper center panels were figured to be shortened 2¼ inches from the theoretical length. These two chord panels were, therefore, shortened 3 inches each, and the so obtained opening of 6 inches was expected to be reduced in this three-hinged arch condition to 3¾ inches. By an application of a compressive strain of 370,000 pounds in these middle panels (which stress was actually applied by hydraulic jacks), the original opening of 6 inches was supposed to be obtained, and the arch then to be closed as a two-hinged arch. The proper corrections for the variations in temperature of course had been figured. The lower panel point was closed a little below normal temperature with ¼-inch opening. At a normal temperature in the three-hinged condition 3¾-inch opening was obtained, which opening, by the application of about 370,000 pounds, was increased to 6 inches. By thus weighing the strain in the upper chord of the center of this arch, all undesirable strains

due to cantilever erection are eliminated from the structure, and the condition of the strains in the structure made to correspond with the figures."

After this work was finished it was discovered that a German engineer had conceived and adopted the same method of closing up a bridge arch, but entirely unknown to the Pencoyd Company's engineers—another example of the simultaneous invention of an important principle by persons widely separated and unknown to each other.

To show the wonderful degree of accuracy attained in the preparation of the materials, in the measurements at the river in locating the abutments, and in the erection of the bridge, we quote from a letter from the engineer in charge of the work, reporting to his company the success of the plans for closing up the arches:

"When the last bottom chords were put in place there was just $1\frac{1}{4}$ inches clearance between the faced surface or $\frac{1}{4}$ inch clearance for the pin. The temperature was a little below 60°. This shows that our measurements and the shop work were practically exact. The alignment and the respective elevations of the two halves at the center were so nearly right that they were pulled into line with a steamboat ratchet. The toggles were not used at all except to slack off after the center pin was driven. The work all came together in a most gratifying manner.

"ATBARA RIVER BRIDGE OVER THE ATBARA RIVER.

"Bridge consists of seven spans 150 feet each, which, due to local conditions, had to be erected without false-work.

"One span was put up temporarily on shore, and the first river span hung out from this and erected by a steel traveller running on top chord and by anchoring the first span down with about 60,000 pounds of steel rails. Then, after the removal of the temporary span, the second river span was erected in the same way, using the first one as an anchorage, etc.

"To overcome the deflections of the spans and the effect of the camber on the position of the end which had to be coupled up over the far pier, the ends were raised 2 feet by

shortening the coupling bars over the pier carrying the anchorage span and the cantilever span. The end shoes were then figured to land $4\frac{1}{2}$ inches above the piers. The actual distance measured varied from 4 to 5 inches.

"While single spans have previously been erected this way by building out cantilever from both shores and closing in the middle, it had never before been attempted to erect a large number of spans this way by hanging each span out as a cantilever for its full length.

"DELAWARE RIVER BRIDGE OF PENNSYLVANIA RAILROAD COMPANY.

"Approaches 2,468 feet long, three fixed spans of 533 feet c.–c. end pins, one draw span of 323 feet c.–c. end pins, all double track.

"The fixed spans were so designed that no eyebar was tapered more than $\frac{1}{20}$ inch per foot, and that the eyebars in the same panel have practically the same taper; also that all members are absolutely straight when they get their maximum strain. This reduces the secondary bending strain, due to the use of a secondary system, of the members considerably (in the end posts over 33 per cent.). The roller end rests on seven cast-steel segmental rollers 18 inches diameter, which are held in position by a gear tooth at each end of the middle roller. The four webs of the chords and end posts are prevented from shifting sideways by vertical diaphragms near each pin hole. The floor was put in place after the trusses were swung entirely free. All stringers were kept about $\frac{1}{16}$ inch long, and the connection angles had a 6-inch leg against the floor beam with rivets as far as possible away from the stringers. Through this arrangement the pull on the connection of the stringers to the floor beam, due to the stretch of the lower chord of the main span (about 3 inches), was overcome.

"The draw span was entirely center-bearing. This is the heaviest draw where the center-bearing construction has been used and has a great many novel features in the machinery. Entirely new is the counterbalanced latch, which is provided with a wheel at the lower end and the

catch for which is so arranged that, if the draw gets to the closing point with too fast a speed, the latch will jump over the opening without jarring the bridge."

As an illustration of the remarkable progress made in recent years in the field of bridge and other structural engineering, and the advanced position attained by the Pencoyd Iron Works in this important field, as attested by the great works above described, especially the Niagara Falls and Clifton Bridge and the Delaware River Bridge, the Franklin Institute awards to the Pencoyd Iron Works the Elliott Cresson (Gold) Medal.

Adopted at the stated meeting of the Committee on cience and the Arts, held Wednesday, May 2, 1900.

JOHN BIRKINBINE, *President.*
WM. H. WAHL, *Secretary.*

Countersigned by
H. R. HEYL,
Chairman Committee on Science and the Arts.

THE UNITED STATES GEOLOGICAL SURVEY.

[*Being the report of the Franklin Institute, through its Committee on Science and the Arts, on the exhibit of the U. S. Geological Survey at the National Export Exposition, held in Philadelphia, October–November, 1899. Sub-Committee.—Theo. D. Rand, Chairman ; Persifor Frazer.*]

HALL OF THE FRANKLIN INSTITUTE,
[No. 2112.] PHILADELPHIA, April 4, 1900.

The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, to which was referred the exhibit of the United States Geological Survey at the National Export Exposition, 1899, would respectfully report as follows:

For the reasons stated in the report of the Committee on Awards of the National Export Exposition, 1899, in reference to this subject, a copy of which is hereto annexed, the

Franklin Institute awards the Elliott Cresson Medal to the United States Geological Survey.

Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, May 2, 1900.

JOHN BIRKINBINE, *President.*
WM. H. WAHL, *Secretary.*

Countersigned by
H. R. HEYL,
Chairman Committee on Science and the Arts.

APPENDIX.

Copy of Report of Committee on Awards at the National Export Exposition, 1899, on the Exhibit of the United States Geological Survey.

The large space occupied by the United States Geological Survey is richly and instructively filled with the products of the industry of this useful branch of the government.

The exhibits of the Survey comprise maps, photographs, publications and a typical series of rocks.

I. The maps are (*a*) geographical; (*b*) topographical, in contour curves or in relief; and (*c*) geological and statistical, *i. e.*, colored to represent the geological structure and the distribution of deposits of economical value. Besides the above are vertical sections where these seem of advantage to the comprehension of the subject.

In all these maps the best methods and workmanship of modern cartography have been employed. For the topography, the system of contour curves displayed in the large atlas maps of the Hayden survey retains in the later maps an equal excellence of finish, but represents a greater accuracy of field work.

There are five specimens of relief maps reproducing (1) the United States on a scale of 1 inch to 12 miles horizontally, and to 1·2 miles vertically, the vertical scale being exaggerated to ten times the horizontal for the purpose of better marking the relief; (2) the Atlanta-Chattanooga district; (3) Nebraska; (4) Tennessee; (5) Connecticut. These models show the perfection to which Prof. J. P. Lesley brought this kind of work in the late Second Geological Survey of Pennsylvania.

A photograph of one of these models, appropriately illuminated, illustrates the device of Professor Lesley for distributing the comprehensive knowledge imparted by these instructive plans as widely as the printed pages of the reports.

In all these maps the accuracy of registration of the several parts upon each other, as well as the constancy of the coloring of the different sections, are worthy of special attention because they indicate the successful solution of two of the most difficult problems in section map making.

A large lithographic press in another part of the building is in active operation, under the direction of the United States Geological Survey.

II. The photographs of the United States Geological Survey have long been famous. In no other national geological survey has photographic illustration been so lavishly and judiciously employed to illustrate the text of the technical studies. But besides this purpose, the splendid colored transparencies of Mr. J. K. Hiller, presenting in brilliant natural colors the Grand Cañon of the Yellowstone Park, and another typical Western view, are in the front rank of their branch of the photographic art.

III. The publications of the Bulletins and Annual Reports of the Geological Survey, among which are included the statistical records of the mineral industry down to the end of the year 1898, exhibit the information given to the people since 1880. The only criticism to be made is the arbitrary adoption of this last date as if it were the commencement of national geological work here, though of course this choice could be justified by the present title of the service. In point of fact, however, the publications which first called the attention of the world to the admirable work this country was doing in the systematic study of her resources, and which made possible the organization of the present, were issued for ten years anterior to 1880.

IV. Following the example first set in Germany, the Survey has prepared a series of 150 specimens of typical rocks whose names recur frequently in the reports. The value of such collections cannot be overestimated. They

make clear the descriptions of complicated geological conditions and put an effective check upon that natural enemy of geological science, the petrographic name-maker.

In the sense and for the purpose of a demonstration to the public of the usefulness and industry of a great public work for which the public pays, this exhibit is deserving of the highest praise, and your committee recommends the silver medal and a diploma, the highest award within its gift.

It recommends, in addition, the reference of this exhibit to the Committee on Science and the Arts of the Franklin Institute, for further investigation with a view to special reward of merit.

(Signed) THEO. D. RAND,
PERSIFOR FRAZER,
Judges of Awards.

Mining and Metallurgical Section.

Stated Meeting, held Wednesday, October 10, 1900.

THE CHEMISTRY AND PHYSICS OF CAST IRON.

Being a Continuation of the Discussion of MR. KREUZPOINTNER'S paper entitled "RIDDLES WROUGHT IN IRON AND STEEL." See *Journal of the Franklin Institute*, May, 1900.

PROF. HENRY M. HOWE (Correspondence):—After considering Mr. Outerbridge's contribution to the discussion of Mr. Kreuzpointner's paper, I should like his answers to the following inquiries:

(1) What composition do you think gives the strongest cast iron? What the highest combination of strength with ductility?

(2) How does the following statement of the relations between the composition and properties of cast iron strike you?

We may regard every graphitic iron as consisting of two distinct parts: (1) its graphite, and (2) its metallic part, which is everything except the graphite. Its metallic part

is essentially steel or white cast iron, according to its combined carbon. Hence it consists essentially of ferrite and cementite, intermixed as far as they go in the ratio of 7 : 1 to form pearlite, the excess of either ferrite or cementite existing in the "free" or "structurally free" state.

We know that steel reaches the greatest tenacity with about 1 per cent. of carbon; as the carbon departs either way from this quantity, the tenacity diminishes. If we apply this to cast iron, then the metallic part reaches its greatest strength with 1 per cent. of carbon, and all carbon in the metallic part in excess of 1 per cent., *i. e.*, all combined carbon in the cast iron as a whole in excess of 1 per cent., is a source of weakness. It is also a source of brittleness and hardness.

All graphite causes weakness and probably brittleness. It is a foreign body, simply breaking up the continuity of the iron, and, itself weak, it must weaken the iron.

In short, all carbon in excess of 1 per cent., whether combined or graphitic, weakens the metal.

By varying the silicon and manganese, the pouring temperature and the rapidity of cooling, we can vary the distribution of the carbon between these two states, and thus minimize its harm; we can for every given percentage of total carbon distribute the carbon between these two states so as to minimize its harm; but the smaller the excess of total carbon over 1 per cent., the less is the harm which we have to minimize, and consequently the less the minimum harm.

If I am right, then the less the total carbon (provided it be not under 1 per cent.), the stronger is it possible to make the cast iron by suitable adjustment of the carbon between the graphitic and combined states.

We may expect that the same is true of ductility; all combined carbon must lessen ductility; we should expect graphite to lessen ductility, because it is a foreign body breaking up continuity; but this case is not so clear, for the reason which causes the leaves of a pamphlet to be more flexible as a whole than a sheet of pasteboard of like total thickness.

In this view the merit of the air furnace is that it effectively lessens the carbon of cast iron; the cupola does this to a much smaller extent, because the molten iron has an excellent opportunity to recover carbon in the bottom of the furnace.

In this view the capital defect of the iron blast-furnace, as an instrument for making foundry cast iron, is that it nearly saturates the iron with carbon, or at least gives it far more carbon than is consistent with the greatest strength, or the greatest combination of strength with ductility. It is hard to see how this fault is to be remedied within the furnace itself, since the desulphurizing action of the furnace, which cannot be dispensed with, is apparently part of the carburizing action. Both apparently take place in the crucible of the furnace, and both depend upon the same condition, viz., that the bath of molten iron in the crucible is penetrated by a solid column of incandescent coke, with the carbon of which the molten iron rapidly saturates itself, nearly or fully. This same carbon removes the sulphur from the iron, apparently, by the reaction

$$FeS + CaO + C = Fe + CaS + CO.$$

So, too, the capital defect of the cupola furnace as an instrument for making strong castings is that the molten iron in like manner greedily absorbs carbon from the fuel over which it runs at the bottom of the furnace; so that, no matter how little carbon the charge contains initially, as it issues from the cupola it seems inevitably over-rich in carbon.

In these very hastily written remarks, for brevity I leave out of account variations in the condition of the combined carbon, between the states of martensite and cementite, the difficulties of casting metal of special composition, etc., confining myself strictly to the points here raised.

MR. OUTERBRIDGE:—I beg to answer Professor Howe's questions as follows:

A. 1. (*a*) The first query is too general to admit of a definite answer. The "strongest iron" for a casting of, let us say, 1,000 pounds weight and 4-inch section in its thick-

est part, would not be the strongest iron for a casting of say 50,000 pounds weight and correspondingly heavy section. Conversely, the strongest iron for the larger casting would not be the strongest iron for the smaller one.

A. 1. (*b*) Cold-blast charcoal iron combines in the highest degree, strength with ductility.

A. 2. Professor Howe's statement of "the relations between the composition and properties of cast iron" strikes me as ingenious but fallacious.

Reasoning by analogy is (like circumstantial evidence) apt to be misleading, unless all the facts are known. This is especially the case when we attempt to compare an exceedingly complex alloy, like cast iron, with a more homogeneous metal like steel.

Even when we confine our analogies to steel itself we may go astray. For example: It was formerly thought that manganese, except in very small quantity, was deleterious to the quality of steel. Hadfield demolished this old belief by his brilliant investigations, producing a whole series of high-manganese steels incorporating at least ten times the quantity of manganese formerly thought to be permissible (or even possible) in steel, creating a new metal having extraordinary toughness and hardness, qualities usually regarded as more or less antagonistic.

Chemical science teaches us that two or more elements may unite together in several different proportions to form definite compounds (*e.g.*, $FeO.Fe_2O_3$, etc.). We cannot say, therefore, that because "steel reaches the greatest tenacity with about 1 per cent. of carbon * * * all carbon in excess of 1 per cent., whether combined or graphitic, weakens the metal." All our knowledge of cast iron disproves this assertion. The strongest and most ductile pig iron is made with charcoal fuel and cold blast. This strong iron is comparatively rich in carbon, both combined and graphitic, and contains smaller percentages of silicon, sulphur and phosphorus than pig iron made with coke in modern hot-blast furnaces. Combined carbon in cast iron causes brittleness only when present in such large proportion that the fracture shows a mottled or white crystalline structure. In

smaller proportion it gives strength to pig iron. The best hot-blast coke iron is a weaker and more brittle metal than the best cold-blast charcoal iron.

I differ entirely with Professor Howe in the concluding sentences of his statement regarding the influence of carbon in cast iron. I also differ with him as to the reason why air-furnace iron is superior to iron melted in a cupola. I attribute the superiority of air-furnace iron to quite another cause, viz., the avoidance of blowing air through the molten iron and consequent avoidance of iron oxide in the molten metal. I am also compelled to differ with Professor Howe regarding his assertion that "the capital defect of the iron blast furnace as an instrument for making foundry cast iron is that it nearly saturates the iron with carbon, or at least gives it far more carbon than is consistent with the greatest strength, or the greatest combination of strength with ductility."

I believe that the strongest and most ductile cast iron is that which contains a maximum of carbon (about one-half combined and one-half graphitic) and a minimum of all other elements except iron.

MR. WM. R. WEBSTER:— I desire to thank Mr. Outerbridge for his complete answers to my questions on cast iron, in his first paper, but I do not agree with his conclusions from the tests he refers to on annealed test bars of cast iron. These bars give more deflection after being annealed than before, and, as he has already stated, their breaking strength was less. I think he will also agree that this material, in its annealed condition, will withstand shock better than before annealing. He has made out a very good case, showing the similarity between annealed cast iron and annealed steel, for in steel, when it is properly annealed, we have a reduction in strength, an increase in elongation, and also an increase in reduction of area. The material is much better fitted to withstand shock.

The other point, as showing the difference between cast iron and steel, in that the size of the grain of the cast iron depends on the mass of metal in the castings of iron, and that this difference in the size of the grain does not take place in steel, I do not agree with either.

The difference does exist in steel, but not to such an extent as in the cast iron, and, as a general thing, in steel the castings are annealed, and this breaks up the large grain and produces the fine structure so much desired. Sir Henry Bessemer, some years ago, by slowly cooling a mass of molten steel, produced a very large grain in the metal, and, I think, taking everything into consideration, Mr. Outerbridge will have to modify his conclusions in both of the above cases.

I am pleased to note that the Association of American Foundrymen are now agitating the question of having our trade schools instruct the young men in chemistry pertaining to cupola practice, and also that Mr. Outerbridge is one of the members of their committee to carry out this work. I take this to indicate that the foundrymen will, from this time on, give freely what information they have on the subject that they propose to have taken up by the young men at our trade schools. If they do not do this, they will, of course, make a dismal failure. We all know that a few years ago our foundrymen were inclined to get all they could from their competitors, but to give nothing in return, treating all matters pertaining to their business as trade secrets; but, as I said before, the indications now are that they are going to take a different course from this time on.

I know of no better channel through which to instruct our young men than the Franklin Institute, and with this in view, I am going to ask Mr. Outerbridge some leading questions in regard to the foundry chemistry of to-day.

Before doing so, I would like to state that I understand, of course, the difficulty of properly interpreting the results of our tests on cast iron, for, in the first place, if we take tension tests and reduce all the results to pounds per square inch, the results depend very much on the size of the casting from which the test-piece has been prepared and location from which it was cut, as Mr. Outerbridge has explained in his previous remarks. On the other hand, if we take transverse tests for our records, we will find all sorts of bars in use; for instance, 1-inch square bars held on supports 12 inches apart and 24 inches apart, and 1 inch by 2 inch bars

placed on the side and placed on edge; supports, 24 inches apart; then we have the hexagonal bar, used by Mr. Whitney, which he considers has special merits for their class of work. The records of all these transverse tests are generally given in merely the center-breaking load, and it is not an easy matter to compare one with the other without doing some figuring.

I also understand that even after we adopt any particular size of test bar and have our records of tests in shape, we cannot tell directly from the results what the character of the metal will be in a large casting, a medium casting or a small casting; we must estimate from the results of the tests on a 1-inch square bar; for instance, as to what the results will be in the different sized castings.

I would now like to ask Mr. Outerbridge if in his experience, knowing the chemical composition of a series of 1-inch square test bars, made under the usual conditions of practice for one grade of metal, he can, from the chemistry, tell what the breaking load would be for these bars.

(2) If, having the breaking load of these bars, the chemical composition and the deflection of the bars, he can estimate closely what the results of such metal would be in large castings, small castings and medium-sized castings.

(3) In making up the mixtures for the cupola, do you depend at all upon the fracture of the pig iron used, or do you treat the whole matter as just so much iron, carbon, phosphorus, sulphur, etc., irrespective of what the fracture of the metal may show?

(4) How closely can you estimate, from the composition of the mixture charged in the cupola, what the composition will be of the metal tapped from the cupola; in other words, what changes will take place in the melting of the iron?

(5) Can you so arrange your cupola mixtures as to produce a casting of a given chemical composition that you aim at to start with?

(6) If you can carry on your work, as indicated above, I would like to ask if you can estimate the strength of your test bars from the chemical composition of your charge,

making allowances, of course, for the changes that occur in melting the metal.

(7) As a final question in this line, I would like to ask what elements you use in estimating the strength of your test bars, and the general method of doing this work; that is, the amounts per unit for the elements that you consider, and how these figures are modified, owing to the relation of one element to the others.

I think the above information would make a very fair starting point for our young men, and also for a good many of the older ones here present. I do not mean to impose on Mr. Outerbridge's good nature too much, or ask him to give away any of their trade secrets, but if the foundrymen are going to instruct the young men, they must give them the best information they have on these subjects, and I believe that in the end all would be gainers by doing so.

In 1895 I gave the following proposed scheme* for the study of the physics of casting to the American Institute of Mining Engineers, and knowing that there has been considerable advance in the process since that time, I would

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*NOTE ON A PROPOSED SCHEME FOR THE STUDY OF THE PHYSICS OF CAST IRON.

By William R. Webster, Philadelphia, Pa.

In view of the great interest now taken in the tests of cast iron and details of foundry practice, with the number of investigators at work and recent improvements in the methods of research, it would seem that the time is ripe to attempt the solution of some of the many problems with which iron founders have to contend. Recent papers and discussions on these subjects have opened up a large field for investigation, and have emphasized the importance of many considerations generally overlooked. With the view of promoting a comprehensive and systematic discussion, I have attempted to tabulate, in convenient form, some of the most important points for investigation, on the general plan suggested, with such good results, by our former President, H. M. Howe, for the discussion on the "Physics of Steel," at the Virginia Beach meeting last year. This table can, no doubt, be modified or enlarged to advantage, and put in shape to serve as a guide or reminder to all who are interested in this line of work.

Suggested Lines for Discussion and Investigation.

I. Correspondence between chemical composition and melting point, fluidity, shrinkage, fracture, chill, micro-structure and other physical properties.

ask Mr. Outerbridge if he would be kind enough to bring these suggested lines for discussion and investigation up to date. I will not take the time to read this short paper, as several copies have been distributed to the members, but would be greatly obliged to any of them who would assist in bringing this matter up to date in all respects.

In my list of questions to Mr. Outerbridge, I omitted the following:

What is the best check test you know of, that can be made quickly before pouring the metal, that will show if it is suitable for the castings for which it is intended? In this I refer to some simple test that will show the physical character of the metal, similar to the ladle test used in melting steel in the open-hearth furnace.

In steel there is always more or less trouble from the oxide of iron. This also gives trouble in cast iron, and I would like to ask, what is the best method of getting rid of the oxide of iron in cast iron, and how long has it been in use?

II. *Influence of:*

<table>
<tr>
<td>(1) Cupola mixture, use of steel and other scrap, oxidized or clean material,
(2) Manner of melting, flux, etc.,
(3) Casting temperature,
(4) Manner of handling melted metal and method of casting,
(5) Size and form of casting,
(6) Kind of mould, green sand (under different conditions of ramming, amount of moisture, and skin-dried), dry sand, loam and chills,
(7) Rate and mode of cooling castings,
(8) Manner and temperature of heating for annealing,
(9) Additions of nickel or aluminum,</td>
<td>on</td>
<td>A. Fracture.
B. Micro-structure.
C. Physical properties.
D. Shrinkage.
E. Chill.
F. Residual stress.
G. Condition and quantity of carbon and other elements.</td>
</tr>
</table>

III. *Segregation as affected by:*

(1) Composition.
(2) Casting temperature.
(3) Rate of cooling.
(4) Size and shape of casting.

MR. OUTERBRIDGE:—For the sake of brevity I think it will be advisable to group several of Mr. Webster's questions together in my replies thereto. With regard to his deduction from the records of annealed and unannealed test

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IV. *Blow-holes, their volume and position as affected by:*

(1) Composition.
(2) Casting temperature.
(3) Casting pressure.
(4) Rate of cooling.
(5) Size and shape of casting.
(6) Special additions.

Instead of giving a review of what has been written on the most important of the above headings, I have induced several investigators and experts to contribute the results of their work and opinions. If these are fully discussed, and followed up by the results of others who are working in the same line, we shall soon accumulate a large amount of valuable material. That such material already exists there is no reason to doubt.

Several works have employed chemists, and struggled with these problems for years, but each one carefully guards the results; and at the present time many seem disinclined to add theirs to the common store. But, if they could be induced to make their methods and results public, by freely discussing them before this Institute, they would be well repaid by the assistance they would receive through such an interchange. Nobody is as wise as everybody; and nobody loses, as a general rule, by a generous frankness which secures the criticism and help of others. The possible loss through giving to competitors a few shop secrets is really trivial in comparison.

I am fully convinced that the relations between the chemical constitution and physical character of cast iron are much closer than is generally admitted to-day. If proof of this is wanted, we have it in the success of those who have given up the old rule-of-thumb methods in running their foundries. There is no doubt that, in a full discussion and investigation of this kind, new data will be brought to light which, in connection with the results of the valuable researches already made, would enable us to make tables and lay down rules for the founder's guidance that would be of the greatest value to the makers and users of cast iron. In other words, from a cupola or furnace mixture, of known chemical composition, we could predict with certainty the physical properties of castings of any given size or shape (due allowance being made for change of composition in melting). Or, when certain physical properties were required in a casting of given size and shape, the chemical composition of the different mixtures that would produce these results could at once be given without any of the "cutting and trying" that we now have. This is not too much to expect; and it is not too much to hope that each will do his part in bringing about a result so beneficial to all. [*Transactions of the American Institute of Mining Engineers*, Vol. XXV, 1895.]

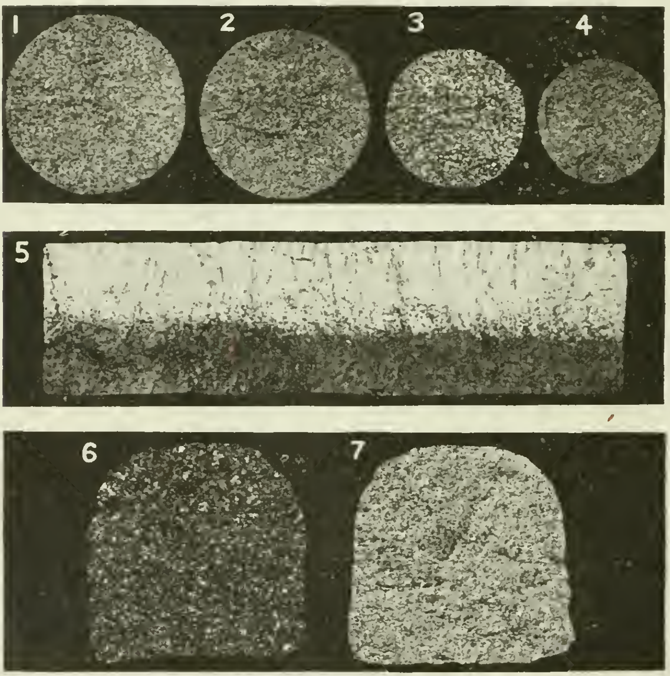
bars of cast iron, given in my first communication, that, notwithstanding the decrease in strength of the annealed bars, they were better able to withstand shocks, as indicated by an increase in deflection, I would say that a calculation of the "resilience" of the bars, made by Prof. J. B. Johnson's rule, shows a large decrease in resilience of the annealed bars, due to the fact that the increase in deflection was far less, relatively, than was the decrease in strength. With regard to Mr. Webster's next point, I would simply call attention to the wording of my original discussion, in which it appears that, in referring to the great difference in grain, or fracture, of cast iron in large and small castings, I said, "no such great difference exists in steel castings," but did not say that there is no difference in grain in large and small castings made from one ladle of molten steel.

Replying to questions 1 and 2, I may say that for many years past it has been my aim to produce castings, day after day, varying from the smallest sized pulleys with rims about a quarter of an inch thick, up to immense machinery castings weighing 40 or 50 tons, and requiring very different mixtures of iron, in which the test bars shall not vary in strength more than 5 per cent. from the predetermined standards of strength (transverse and tensile) for castings of any given kind. I am sure, from a review of records extending over a good many years, that the average variation is less than 10 per cent., and such variations would probably be still less if it were practicable to melt only one grade of metal in a cupola in one heat. Commonly, three different grades of iron are melted in one heat, viz., soft iron for pulleys and light work, moderately strong iron for "medium" work, and very strong iron for special castings, generally of large size. The transverse strength of 1-inch square test bars 15 inches long, broken with supports 12 inches apart, varies from about 2,000 pounds for soft iron to 4,000 pounds (center load) for strong iron, and the tensile strength ranges from about 20,000 pounds to about 40,000 pounds per square inch.

(3) The fracture of the pig iron is carefully noted when the iron is received in the yard, not so much as a guide to

subsequent mixtures in the cupola, but because it is an indication of the working condition of the furnace from which the iron was purchased. It may be stated, however, that more attention is paid to the fracture of the pig iron in making charges for pulleys and small work than in making mixtures for large castings.

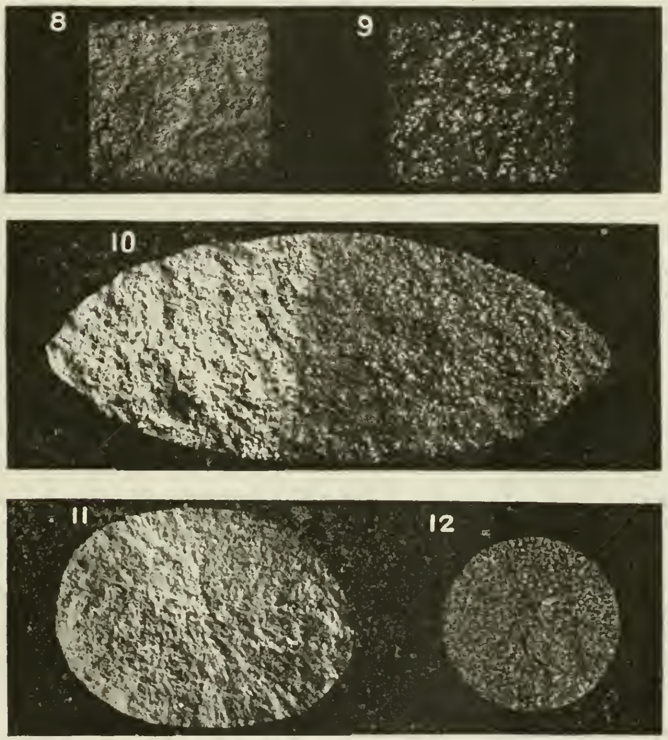
(4–5) The resultant castings ordinarily agree very closely with the composition of the mixture charged in the cupola,



as a certain allowance is always made for burning out of the metalloids in melting. For example, a casting, such as a car wheel, which should contain by calculation from the mixture 0·7 per cent. of silicon, will rarely, if ever, be found to vary more than $\frac{1}{10}$ of 1 per cent. either way from the standard. In like manner, a casting made from a mixture of different kinds of pig iron having very different proportions of silicon, but averaging $2\frac{1}{4}$ per cent. of that element, will

rarely be found to vary more than $\frac{1}{4}$ of 1 per cent. from the standard.

(6) The strength of test bars depends largely upon the size of the bars. Two bars cast in the same mould from the same ladle of iron, from a good mixture, one bar being $1\frac{1}{4}$ inches diameter and the other $1\frac{3}{4}$ inches, both turned to the same size, say 1·129 inches (= 1 inch area), will show a variation



of about 20 per cent. in the tensile strength of the two bars, the larger bar being the weaker, assuming, of course, that both bars are gray iron. I have already stated that the strength of the test bars can be approximately estimated from a knowledge of the composition of the mixtures.

(7) I regard the element silicon as the most important of all in determining the question of strength of foundry

iron, not because this element imparts strength or weakness to iron *per se*, but because it controls the condition of the carbon, whether graphitic or combined.

Other elements, such as phosphorus, sulphur, manganese, etc., all exert their influence, but it is not very difficult to guard against the danger of introduction of any of these elements in injurious proportions, while some of them, when present in moderate amount, are beneficial.

In reply to Mr. Webster's final questions, I would say that the kinds of foundry tests which shall show the physical character of the metal before pouring depend so largely upon the character of the castings to be made and kind of metal melted that the methods adopted in one establishment may not be at all suitable to another. So far as I know, there are few general foundries where rapid tests are made during the run of iron, and the consequences of such neglect are sometimes serious, for castings are poured from metal unsuitable for the work, this fact not having been known at the right moment to prevent the error.

Finally, I may say that I am convinced that the presence of iron oxide dissolved in the molten metal is a factor which is commonly overlooked, and is to be feared, especially in strong iron mixtures. The best deoxidizer with which I am familiar is ferro-manganese, a metal containing about 80 per cent. manganese, which may be added either in the ladle or in the cupola in the proportion of about 1 pound to 600 pounds of iron. The effect is to increase the strength and ductility, to decrease the chill, and to darken the gray color of the fracture in high-chilling iron mixtures. This discovery was first brought to the attention of metallurgists in an address given at the Franklin Institute in February, 1888, on "Pig Iron, Including the Relation Between Its Physical Properties and Its Chemical Constituents."*

Since that time the beneficial effects of ferro-manganese as a deoxidizer and desulphurizer in certain iron mixtures have become quite generally known, and its extensive

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* *J. F. I.*, March, 1888.

use, especially in car wheel foundries, has followed thereupon.*

DESCRIPTION OF PLATES.

FIG. 1 shows the fracture of a test piece cast from a regular melt of fairly strong iron for machinery castings. The rough dimensions of the bar were 1⅝ inches diameter by 15 inches in length, turned on a lathe to a diameter of 1·129 inches for a length of 7¾ inches between shoulders, and pulled on an "Emery" 100,000-pound hydraulic testing machine. The tensile strength was 33,740 pounds per square inch.

FIG. 2 shows fracture of fine-grained, soft iron, made in a special manner for special work. The rough dimensions of the piece were $1\frac{5}{16}$ x 1¾ x 13½ inches, turned to a diameter of 1·06 inches for a length of 8 inches. The tensile strength was 29,794 pounds per square inch.

FIG. 3 shows comparatively coarse-grained fracture of soft iron for pulleys and small work. Rough dimensions 1⅝ inches x 15 inches, turned to a diameter of ·935 inch for a length of 7·25 inches. Tensile strength, 19,708 pounds per square inch.

FIG. 4 shows fracture of a square bar cast from nearly the same grade and quality of cast iron as *Fig. 1*. Rough dimensions, 1 x 1 x 15 inches. This bar was first broken transversely on a testing machine with supports 12 inches apart. The transverse strength was 4,200 pounds, center load. One of the broken pieces was then turned to a diameter of ·813 inch for a length of 4 inches between shoulders, and pulled. The tensile strength was 40,116 pounds per square inch. The greater strength as compared with *Fig. 1* test piece was due to the smaller dimensions of the bar.

FIG. 5 shows fracture of a "chill test piece" cast in a green sand mould, with an iron "chill-block" on one face. This casting was made from the same ladle of iron as *Fig. 1* tensile test bar. The metal has sufficient chilling property for making chilled cast-iron car wheels and contains no charcoal iron.

FIG. 6. shows fracture of a pig of foundry iron, graded "2^x," made with mixed anthracite and coke fuel. It contained 1·7 per cent. silicon.

FIG. 7 shows fracture of a pig of foundry iron, graded "2 plain," made with coke. It contained 2·75 per cent. silicon. These samples of pig iron show the risks which founders incur when relying upon furnace grading of pig iron by fracture.

FIG. 8 shows fracture of a test bar 1 x 1 x 14 inches cut from the outer portion of a cubical block of cast iron 15 x 15 x 15 inches. This block was first planed on all faces and then cut into eight slabs, 1 x 14 x 14 inches; these slabs were each cut into eight strips, or bars, making 64 test bars in all, 1 x 1 x 14 inches each. The bars were numbered serially and all

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* The speaker illustrated his remarks with an interesting collection of specimens of pig iron, test bars and castings. By the aid of a "megascope" the physical characteristics of freshly fractured surfaces of different grades of metal were shown by casting their images, greatly magnified, upon a screen. A few of the more striking specimens have been photographed, and are here reproduced by the half-tone process.—EDITOR.

were broken transversely on a testing machine with supports 12 inches apart. The piece marked *Fig. 8* was taken from the bottom row. It shows a fine-grained fracture and gave transverse strength of 2,878 pounds. center load.

FIG. 9 shows fracture of a test bar cut from near the middle of the cast-iron block ; it shows a very coarse-grained fracture and dark color ; the transverse strength was 1,800 pounds, center load. The average strength of the eight test bars cut from the middle of the block was little more than one-half the average strength of the eight bars cut from the lower part of the casting.

FIG. 10 shows fracture of an arm of a pulley, cast from soft iron similar to *Fig. 3* test piece. A card was laid upon a portion of this casting and the exposed part was briskly brushed with a whisk for about three minutes. The loose graphite lying between the crystals of iron was brushed away like dust, thus changing the color of the surface of the casting from dark gray to almost white, and giving the metal an extremely hard appearance, which, of course, was entirely deceptive. This interesting experiment may be readily repeated upon any freshly-fractured surface of gray cast iron.

FIG. 11 shows fracture of an ingot of white iron, rough dimensions 2 x 1¾ x 10 inches. This metal was exceedingly brittle and too hard to machine ; the white iron bar was placed in an annealing oven, in a closed case containing sand and charcoal, to prevent any decarbonization, such as occurs in making "malleable" iron castings. The combined carbon of the white iron was gradually changed into graphite interspersed in the interstices of the metal. The bar then became quite "tough" and dark gray in color.

FIG. 12 shows fracture of a test piece turned to 1·129 inches in diameter, from the bar *Fig. 11* after annealing. The tensile strength was 47,760 pounds per square inch. A brief description of this interesting and rather novel treatment of white iron castings may be found in the *Journal of the Franklin Institute*, May, 1900, in the discussion of Mr. Kreuzpointner's paper on "Riddles Wrought in Iron and Steel."

MR. ASA W. WHITNEY :—In agreeing recently with Mr. Outerbridge's statement concerning the weakening of the metal of chilled cast-iron wheels by the annealing, which strengthens them as castings, through the relief of the unequal strains of gray plate and chilled tread, I was misled at the time by the correspondence of merely similar tests of mine on 2-inch square bars of gray wheel metal with his 1-inch square bars of low chilling or nearly non-chilling iron. In spite of Mr. Webster's criticism, Mr. Outerbridge's position is apparently correct, as the averages of the two sets of bars give a reduction of resilience of about 13 per cent.

But judging from the fact that ordinary wheel annealing decidedly improves in resistance to drop tests even gray iron centers for steel-tired wheels, it is evident that the

testimony of square bars is not final. I regret that I have never tested by flat bars the point now raised by Mr. Outerbridge. But it seems probable that the kind as well as the degree of effect of annealing depends upon the method and completeness of the process as well as upon the character of metal and of the cross-section treated. A flat bar, even of the same sectional area as a square one of the same iron, does not figure out to the same modulus of rupture and resilience unless cut from a larger casting. Even in gray castings, as pointed out, and illustrated by photogravures, in my paper on "Transverse Strength of Chilled Car Wheel Metal,"* the effect of a difference in the relations of the direction of quickest cooling to that of stress can be shown without a change of cross-section. It is likely that the effects of annealing on flat bars of different gray compositions will be found more or less beneficial in reasonable agreement with the indications of practice. Estimating from the calculated modulus of elasticity of Mr. Outerbridge's bars and from my tests on unannealed square, flat and hexagon section wheel iron bars, it appears that a gray iron only slightly harder than his will increase at least 5 per cent. to 10 per cent. in resilience by ordinary wheel annealing if cast $\frac{3}{4}$ inch deep by 2 inches wide and tested flat. In wheel iron bars chilled solidly white from opposite sides, even if of $1\frac{1}{2}$ inches square cross-section, the difference due to a change of relation of stress to the direction of quickest cooling is far more notable than that caused by the annealing of the 1-inch square bars in question. Averaging the two 1-inch bars in each condition referred to, it appears that annealing effects a loss in transverse strength of 19 per cent., and in resilience of 13 per cent., in spite of increase of elasticity of 30 per cent. (E or factor for modulus of elasticity being reduced from 10,555,000 to 8,074,000). But the greater importance of the effect of a more rapid dissipation of heat in the direction of the depth rather than of the breadth (referring to position of bar in transverse test) is shown by the results of change of position in testing ten

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**Journal of the Franklin Institute*, April, 1897.

aforesaid $1\frac{1}{2}$ square bars. Five were tested with the direction of *slowest* cooling as the depth, or direction of load, and the other five with the direction of *quickest* cooling as the depth. A comparison of the average results of each set shows that changing the direction of depth or load from that in line with slowest to that of quickest cooling effects a gain of 81 per cent. in transverse strength (modulus of rupture) and 175 per cent. in resilience in spite of a decrease of 19 per cent. in elasticity (E increased from 9,173,500 to 10,892,000).

The effect of subsequent moderate annealing would probably reduce the value of E more than the modulus of rupture in the original direction of quickest cooling, thus showing improved resilience.

The great effect of the original rates of cooling upon E, in wheel iron, owing to shapes and sizes, is shown by the following: In a 1-inch square bar, tested with direction of chill as the depth, $E = 15{,}988{,}000$ and modulus of rupture 46,836; while a bar of hexagon section and 4-inch area from same ladle, totally gray (cast entirely in sand), showed $E = 6{,}081{,}500$ and modulus of rupture 60,240, which, with but 11·3 per cent. increase of transverse strength and 3 per cent. decrease of specific gravity over flat chilled bar of same area tested the strong way, gave it a resilience of 103, or 71 per cent. greater. This effect of the direction of quickest cooling is so great that the flat chilled bar referred to above will break, if tested edgewise, at about 2 per cent. less instead of 70 per cent. more than if tested flat, or in direction of quickest cooling. Consideration of the above points leads to the conclusion that wheel iron at least, cast in flat bar or plate form, even though gray in fracture, is given a higher resilience by ordinary annealing because the reduction in the value of E is more important than the reduction of modulus of rupture in the direction tested, which is that of the most rapid dissipation of heat.

Incidentally, it is therefore evident that, in calculating strength and resilience of one form of section in cast iron from another by the proper engineering formula, reference to the modulus of elasticity and to specific gravity is also

necessary. For different compositions reference to relative grain and capacity for chill is required, as these are also affected by the same changes in rates of cooling due to change of section or its relation to stress. As calculation directly from the approximate analysis already gives a measure of success in prediction of relative strength and capacity for chill for standard conditions, I presume further study and experiment will develop formulæ, based on chemical composition, which will more directly give the proper corrections on modulus of elasticity and specific gravity to be made for change of composition as approximately known from the chemically calculated cupola charge.

Mr. Francis Schumann has already given formulæ by which the contraction of any shape or section can be calculated when rate of contraction of any standard test bar is known.

Systematic work on these laborious lines would presumably result in valuable tables and short formulæ.

Resolving of ordinary analysis into a metallographic analysis of the terms cementite, etc., referred to by Professor Howe, would probably at once simplify formulæ for standard conditions.

In regard to wheels that "break asunder with a loud report" if allowed to cool outside the mould without annealing, I can state that a proper application of foundry chemistry has proved such quality to be of unsuitable composition for best results even if annealed, and has made it very rare. For wheel annealing it is not the time of cooling, but, as Mr. Schumann has stated in regard to glass, the uniformity of rate of cooling, which is important for the *relief of strains;* whereas for the *formation of graphite* time is doubtless important. Where the latter occurs to a marked degree the effect upon the physical qualities depends upon the original character. For instance, the white iron bars recently shown by Mr. Outerbridge were improved greatly both in tensile and transverse strength and in resilience by such annealing, which fact also tends to indicate that flat bars of moderately hard iron would be improved rather

than weakened even by severe annealing. In fact, I have obtained best results in annealing of light wheels by using a much higher initial temperature with uniform but quick cooling, two days being sufficient, instead of our former practice requiring three, or that of other makers, who use no fire in pits, and require as many as five or six days.

Concerning Mr. Outerbridge's answers to Mr. Webster's questions 4 and 5, I disagree with the idea that the correspondence is close or uniform between the cupola charge and the casting. In a crucible melt the variations are important, in a cupola much greater, and in an air furnace enormous. Even to the untechnical founder this difference is one of the salient features of foundry experience. And the measure of this difference is, naturally, the very considerable percentage of new iron necessary to continue the same quality. Constant experience for many years with mixtures calculated from complete analyses, and compared with analyzed and physically tested castings, has shown the actual differences for different kinds of casting and conditions. Moreover, the exact average kind of pig required to balance given scrap or pig on hand is easily calculated from such differences, and then subdivided by reference to the kinds and prices of available stock on the market. The results have never indicated any notable amounts or importance of dissolved oxides even in air furnace-melted mixtures for cast iron.

But the impracticability of making up mixtures wholly by calculation from complete analyses of the stock, without a knowledge of the kind of chemical change and the approximate amount of total oxidation which causes this change, is sufficient reason for the limitations in the practice of those who use only partial analyses. In such cases it is necessary to limit the classes of stock much more than in strict chemical practice, supplement analyses and sampling by such considerations as "working condition of the furnace" which made the pig, besides generally admitting that "more attention is paid to the fracture of the pig in making charges for pulleys and small work than in making mixtures for large castings." Even where silicon was sup-

posed to be quite uniform in its oxidation and in its allowable amount, it is now evident that both of these matters depend upon the other elements, particularly the carbon; which latter may range, by experienced adjustment of remainder, from 3·5 per cent. to 4 per cent., even in the line of car wheels of good quality. A well-known argument against foundry chemistry has been that equally good castings of same kind may analyze quite differently, and, *vice versa*, that so-called "practically identical" analyses may be obtained from physically unequal castings. Thus, it is evident that to "guard against" "undue amounts" of certain elements and to attain, also, the proper adaptability at one foundry, which is shown to be possible by the various results of ordinary practice, some fairly accurate knowledge of the relative importance of variations and oxidation is essential. The "moderate amount," which is as vital as is the presence of an element in cast iron, can only be "positively beneficial" to a maximum degree when it is known exactly enough to permit of proper adjustment to other elements by calculation on complete analyses.

In working by chemistry, the total oxidation, which causes an increase in the percentage of iron in the casting over that in the charge, usually with an increase in phosphorus, is most practically important. That is, a variation in the amount of the principal constituent is, in general, more important than any one of the lesser variations causing it. Professor Howe's view of the comparative results of oxidation of cupola and air furnace practice, and, in a general way, the imputation of greater strength to air furnace iron from this cause, being in line with experience, does not tend to substantiate Mr. Outerbridge's explanation of the difference, by reference to dissolved oxides. In fact, the usually greater percentage of iron in the charge for air furnace work, its greater increase by the oxidation of other elements, the long exposure to oxidizing influences and final pouring of a generally harder metal at a lower temperature than such metal from a cupola would show, apparently tend to favor the presence of more oxide in air furnace castings. But in this work, also, experience shows

that in fairly hot fusible cast iron the effect of such oxides is unimportant until chemical method is used fully otherwise. The kinds and amounts of the changes caused by oxidation are greater and more difficult to follow than in cupola work, but the solution of these problems, rather than of very important amounts of oxides, has been already to a large extent accomplished.

In view of the foregoing there appears to be no sufficient proof that the oxides of manganese found in slag or on surface of molten cast iron result from a reduction of dissolved oxides by the original, or by specially added, manganese. Its real effects are, however, practically considered and utilized in my practice of the close application of chemistry. The original manganese in the metal or mixture, besides being oxidized more rapidly than other elements, is notably slagged off by the sulphur. By again restoring it in any way, more sulphur is removed and all ratios altered, the iron being decreased in percentage. The crude way in which it was first used without chemistry led to serious irregularities of quality; and whereas it was supposed to be wasted if put in large receiving ladle or in the cupola charges, I have found it useful according to the principles of my ordinary calculation on the chemistry, in much smaller amounts than originally recommended, either in charges, large ladle, with or without admixture of other material, and with limitations in small ladles. Various conditions determine which is the better way to use it, as also when to omit it.

Regarding quick tests to show quality of iron in a ladle before pouring castings, such are hardly practicable in hard iron. But even a modification of a small chill test might be devised in connection with chemical method, which would be satisfactory in spite of rapid cooling. Ordinarily the last "furnace test" of air furnace practice does not exactly represent the "ladle test," and both are too slow for immediate use. There is a doubtful method which consists in judging by the general shape of water-chilled shots. I believe it was Dr. Blair who mentioned a modification of this, which consists in the use of a sieve,

FIG. 1.—Very hard, but of fair strength, though coarse. A result aimed at by close calculation from complete analyses. Only ·83 per cent. manganese. Solid white without chilling in much larger sections. The effect of chilling one edge (top) is shown in the greater length and definition of crystals from that edge. See p. 346, May, 1900, *J. F. I.*

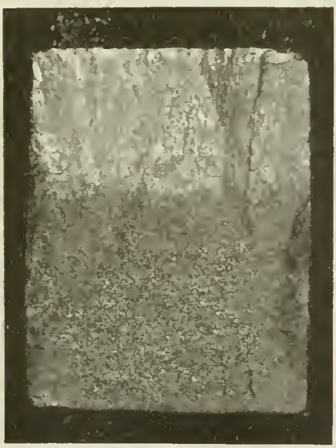

FIG. 2.—Chill test of a calculated low phosphorus mixture of which 97 per cent. was a remelt of tinned and detinned sheet iron and steel. No ferro-silicon or cast iron used. Tin, ·135 per cent.

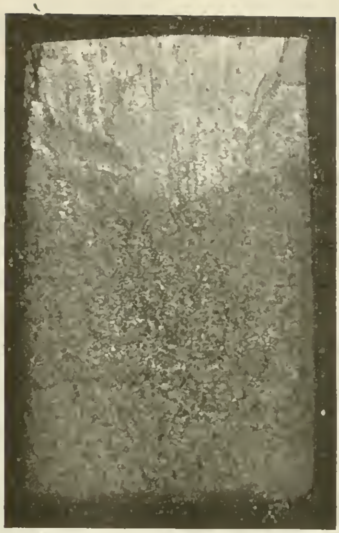

FIG. 3.—Good wheel mixture. 61 per cent. wheel scrap; 16·5 per cent. charcoal irons. No ferro-manganese in charge or ladle. Chill test of first tap.

FIG. 4.—Good wheel mixture. 55 per cent. wheel scrap; 3·9 per cent. charcoal iron; ·1 per cent. ferro-manganese. No ferro-manganese in ladle. Chill test of first tap.

through which the molten iron is dropped, causing it to fly mostly into shot about the size of mustard seed without melting the sieve. I have used this method in obtaining occasionally quick analyses of wheel metal during the heat. But for soft iron very small chill cup tests, cast in iron moulds similar to the "Whitney chill cup" used at some blast furnaces since 1872, would suffice. I have experimentally used, as quick chill cup tests for soft iron, the ingots 4 inches long and ½ inch and 1 inch square, produced by the iron moulds devised by Mr. Outerbridge for investigation of chilled irons. A little modification would make them very convenient tests.

As results of mixtures made up wholly by calculation on complete analyses of component material, I show four photogravures on next page. *Fig. 1* is the very coarsely crystallized white iron sample referred to on page 346 of this discussion, March 14, 1900. It would run entirely white even if cast entirely in sand and of much greater cross-section. The effect of the more rapid cooling by the iron chiller is merely to make lines of crystals more uniform and definite in that direction. *Fig. 2* is from another crucible test for a very low phosphorus wheel mixture to show what could be done with the most unpromising material. Ninety-seven per cent. of the charge was one chunk of sash weight metal made by a change in the method of melting old and new tinned and "detinned" scrap in a cupola. The remaining 3 per cent. brought the calculated change in quality, though it was not in the form of cast iron, ferro-silicon or other magnetizable material.

Figs. 3 and *4* are from cupola melts of regular mixtures for chilled wheels; that from which *Fig. 3* was cast containing 16·5 per cent. of charcoal iron with 61·5 of wheel scrap, while *Fig. 4* was cast from mixture of which but 3·9 per cent. was charcoal iron and 55 per cent. was wheel scrap. The latter indicates much the best iron for heavy wheels, and along with experience goes to show that character of iron does not depend upon physical or chemical history before melting in a calculated mixture, but upon its composition.

As answers to Mr. Webster's questions, submitted to me also, the following condensed summary may not be sufficiently clear, save to those who may have spent many months at least, with very close attention, in the line indicated. Expertness in use, rather than in statement, of my method naturally results from the fact that my views, after three years of study connecting laboratory and foundry work, then developed into methods commercially available, through the daily necessities of the task of controlling both the quality and economies of two to six mixtures aggregating 40 to 100 tons, including chilled and gray castings. The accuracy with which these answers apply must, however, naturally exceed that expected in an examination of the old method whose data is less definite and whose results are more limited for same time and expense.

(1) My practice is to regulate the final adjustments in the composition of the charge from the reported tests of bars and castings of the previous mixture. The strength alone being an insufficient criterion, I do not associate it alone with a definite composition, because there are several which would give the same strength but give different results otherwise. However, I can of course tell the breaking load approximately for many compositions and rates of oxidation of charge.

(2) I can more or less closely. But, as above indicated, my method but rarely requires analyses of the *bar or casting;* but, under the conditions given, the calculated composition of the *charge* would usually suffice; and with some calculation, as well as estimation, the results of size and shape on other attributes as well as strength can be approximately, or, where experience comes in, very closely estimated.

(3) For calculation of the mixture I depend, of course, upon complete analyses only. In order to sample scrap and certain classes of pig, it is of course sometimes most convenient to regrade by fracture before taking the sample for analysis. Also, new lots of well-known classes of scrap are inspected to see if a certain change on the old analysis will suffice, depending upon the proportion convenient to use. Practically, the errors can be kept so small that, besides

considering just so much of each element furnished by the stock, it is practicable to regulate by the minute alterations of ratios suggested by the variations of bars.

(4) The degree of accuracy attainable depends greatly upon the sort of chemical composition of charge, kind and rapidity of melting, and upon the *necessity* for close knowledge of the figures which analysis of water-chilled shots or casting would show. The changes that take place in melting the mixture, depending upon the above-stated conditions, are, in general, oxidation of all the elements, including the iron, which latter, however, is almost invariably decidedly increased in percentage. Though this possible increase is of course greatest where the original percentage is least, its actual increase in careful practice with full analyses and test pieces may be kept to a minimum, thus requiring the minimum amount of new iron and high-priced pig. The effect of oxidation of the other elements has been previously referred to in general, but is specifically considered in each case and kind of mixture calculated. Where necessary the composition of the metal at spout is known with the sort of accuracy which admits of the use of 95 per cent. of scrap in the charge, the unsuitable iron expected at the spout being brought to the proper quality by an already prepared heated charge of two or three kinds of alloys equal in weight to 3 per cent. of the molten iron to be held in ladle. The change in the oxidation and rate of cooling is allowed for.

(5) Very seldom exactly, because even with a proper variety of stock it is often mathematically very difficult or practically inconvenient to adjust the proportions of the various irons to give the composition necessary in the charge. But within limits it is done; the charge as first calculated usually being incorrect, the most convenient alterations are made which will give perhaps notable change in percentages of elements, but whose net result will, by reference to experience and minor principles, properly oxidize to give the required kind and approximate figures suitable for the work. The oxidations occurring in the different kinds of suitable charge compositions are neces-

sarily different and give different, but, by selection, suitable results. Such questions as 4 and 5 are confounded by many in discussing foundry chemistry.

(6) From the conditions mentioned I can, as heretofore shown, fairly estimate the strength along with other necessary considerations of bars or castings. As the latter depend upon other qualities equally with strength, the charge is not made up with that one point in view. In fact, the practical operation is quite the reverse and more direct than that inferred by the question; the observed qualities and variations of bars and castings, and occasionally their analyses, indicate the required alteration to be made on the charge or cupola practice before serious alterations of quality occur.

(7) All of the elements shown by the analyses of all stock used, the effect of all the known conditions, exclusive of fracture or physical qualities of melting stock, saving of course questions of size, dirt, oxides, etc. But since they are not used for the regulation of strength only, the aim being castings, not test bars, the general method of controlling quality of the castings has been sufficiently referred to for the purposes of this discussion, test bars being one of the principal means in following the relation of one element to another. As to "amounts per unit" of strength or other quality, this is now mainly a matter of my experience and takes months at least to learn or to teach in any one line of castings, and can hardly be so expressed. But I have had some success in close calculation of both chill and strength from analyses alone. Though insufficiently developed, one instance covering six irons is quoted by Mr. Thos. D. West,* showing my results in December, 1896, in the matter of strength by means of a valuable, though still imperfect formula, applied directly to analysis.

* "Metallurgy of Cast Iron," 1st ed., p. 525.

Chemical, Electrical, and Physical and Astronomical Sections.

Joint Meeting, held Tuesday, March 20, 1900.

THE ACETYLENE FLAME.

BY EDWARD L. NICHOLS.

In this paper it is not my intention to consider the acetylene flame from the industrial point of view. The literature dealing with the methods of manufacture and with the general technology of this new and important addition to artificial illuminants is already a large one. I propose merely to report the progress of certain investigations upon the properties of the acetylene flame undertaken for the purpose of determining its usefulness in the physical laboratory. Many of these experiments are not completed, for the subject is a surprisingly broad one and new questions are continually presenting themselves in the course of the investigation.

The acetylene flame appeals to the physicist as peculiarly worthy of careful study for the reason that in it he has a fuel of definite chemical composition (C_2H_2), the combustion of which under proper conditions affords a source of light of great brightness and stability and of high actinic value. Although he may expect much from the new illuminant on account of the properties which I have just mentioned, and may see in it new and valuable means of further increasing the precision of photometric and spectroscopic research and of facilitating investigations in many other fields, he soon finds, that the complete control of the acetylene flame, for his purposes, is no simple matter.

INFLUENCE OF AGE AND OF THE MODE OF PRODUCTION.

The illuminating power of acetylene depends to a surprising degree upon its age, and upon the method by which it has been produced. It has been well known for some time

that this gas, when stored for any considerable length of time over water, and I am not sure but the same is true whatever method of preserving it may be adopted, falls off to a marked extent in illuminating power. The following account of my own experience with this phenomenon may be of interest. A gasometer filled with acetylene in the spring of 1899 was allowed to remain untouched for about five months, at the end of which period a comparison was made between the candle-power obtained from it, and that from a flame of new gas, using the same burner and the

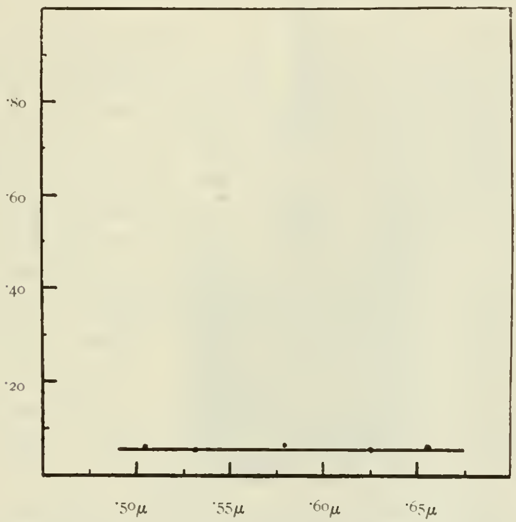

FIG. 1.—Brightness of the spectrum of an acetylene flame from gas stored five months over water (the corresponding flame from new gas being taken as unity).

same pressures. It was found that the brightness of a flame from the old gas was only about six one-hundredths of that obtained from newly generated acetylene. The color of the two flames, compared by means of the spectrophotometer, showed, however, a scarcely appreciable change.

The curve shown in *Fig. 1*, which has been plotted for the purpose of illustrating this point, from measurements made in five regions of the spectrum by one of my assistants, Mr. L. W. Hartman, will serve to indicate definitely

the result of age upon the illuminating quality of the gas. A preliminary analysis showed that the gas contained about 25 per cent. of acetylene.

It is obvious from this example, which may serve to corroborate the experience of others, that acetylene gas must be consumed while still comparatively new if one would avoid loss by the breaking down of the compound, and what is of more importance from the point of view of the physicist, that if we are to employ the acetylene flame in work demanding constancy of illuminating power, the age and condition of the gas will have to be definitely specified.

Experiments to determine the rapidity with which this degenerative process occurs, and if possible to establish the limits of age within which one can use acetylene without being compelled to take cognizance of the changes to which it is subject, are in progress. It is an investigation which will, of necessity, require considerable time, but I hope at some later date to be able to report definite results.

Not only is it true that age affects the quality of the gas, but the process by which it is generated is likewise a matter of some importance. Two distinct methods of bringing about the reaction between water and calcium carbide have been in use. In the first of these, water in small quantities is allowed to fall upon large masses of the carbide. In the second, small masses of the latter are thrown into large quantities of water. In the former process very high temperatures are frequently produced, and at these temperatures the character of the reaction seems to be noticeably modified. Without attempting to go into the chemistry of the matter, which has already been considered by others,* it may be sufficient here to point out that the illuminating power of the gas attained by the second or wet process is considerably greater than that derived from acetylene, or from the mixture of acetylene and other gases which we obtain at high temperatures. To get as definite information as

* See V. B. Lewes, *Journal of Gas Lighting*, 1897, p. 1177.

possible upon this point, gas generated by the dry process was collected in a gasometer of the usual form and was immediately measured both photometrically and by means of the spectrophotometer. For the purpose of these experiments, two burners of similar type were selected, one of which was supplied from a large wet process generator used in the production of acetylene in nearly all of the work to be described in this paper. Between the gasometer and this burner was placed a pressure regulator of a form designed by my colleague, Prof. G. S. Moler.

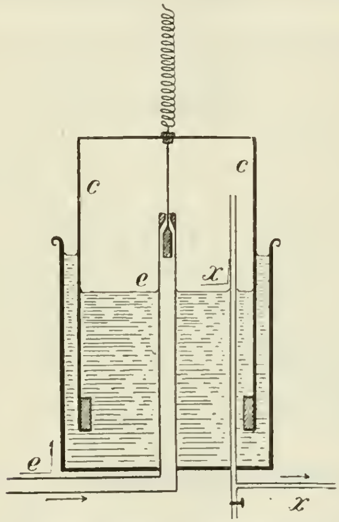

FIG. 2.—Pressure regulator for acetylene.

Although the principle of this regulator is not new, I venture to describe the particular form used in our experiments because of the excellent performance of which it was found capable. The essential features are indicated in the diagram (*Fig. 2*). The bell of the regulator, which is given the cylindrical form usual in gasometers, is considerably overweighted and the surplus weight is counterbalanced by means of a spiral spring attached to the roof of the floating cylinder. The gas is introduced through the pipe *e e*, which rises vertically from the middle

of the base of the gasometer to a point above the level of the water. The upper end of this pipe has a valve with conical seat, which is opened and closed automatically by the rise and fall of the balanced cylinder *c c*. The gas is drawn off to supply burners, etc., through the exit pipe *x x*. The operation of the apparatus, which is quite obvious from the diagram, consists in the automatic opening and closing of the valve already referred to by the rise and fall of the floating cylinder. Observations of the performance of this regulator by means of water manometers placed between it and the large gasometer, and between it

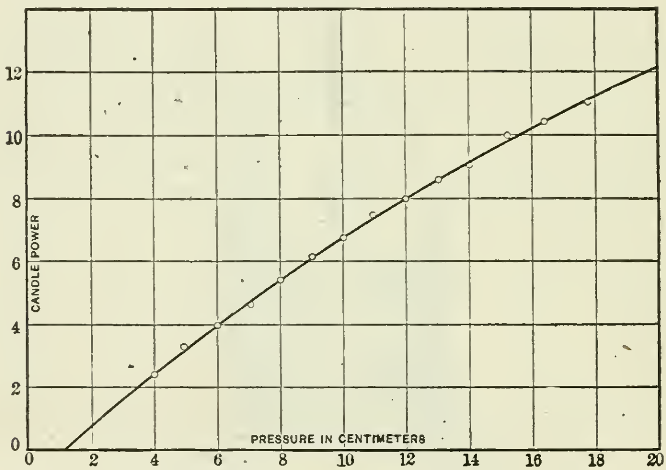

FIG. 3.—Candle-power.—Pressure curve with acetylene.

and the flame, showed that whatever fluctuations might occur in the former, the pressure in the latter rarely varied by as much as one-tenth of a millimeter. The closeness of regulation of this device is ample for all photometric and other experiments in the burning of acetylene gas, since it requires a difference of about 2 millimeters water pressure to produce 1 per cent. of fluctuation in the candle-power of an acetylene flame burning at the usual range between 5 centimeters and 20 centimeters of water pressure. The relation between candle-power and pressure in the case of this gas has already been carefully worked

out. The accompanying curve, *Fig. 3*, which is taken from measurements of Mr. Hartman,* will suffice to refresh the memory of the reader concerning it. With the pressure held within the limits already indicated, no sensible error from this source was to be anticipated. At the other end of the photometer bar the second burner was mounted, and this was attached to the gasometer containing acetylene generated by the dry process.

After measuring the brightness of the flame from the *dry process* gas, the burner was connected directly with the

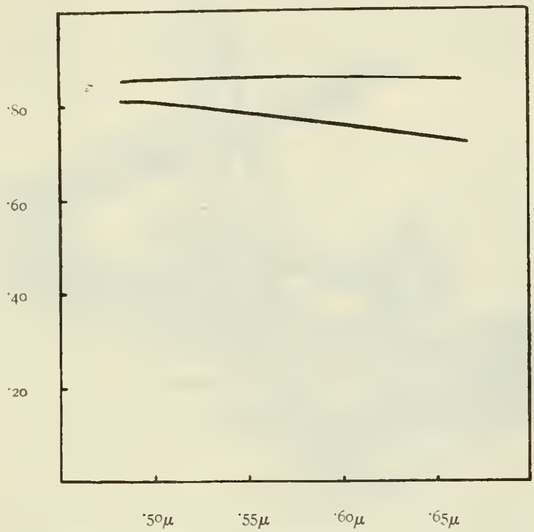

FIG. 4.—Brightness and color of dry-process flames.

large gasometer, the pressure was brought to the same value as that under which the *dry process* gas had been burned, and the measurements were repeated.

From photometric comparisons of the two burners under the conditions indicated above, it is possible to obtain the candle-power of the *dry process gas* in terms of that of ordinary acetylene produced by the wet process consumed under like pressure and in the same burner. This measurement, which was made by Mr. Hartman at my request, showed

* Hartman, *Physical Review*, IX, 184 (1899).

the candle-power of the dry process gas to average about 80 per cent. of that obtained from acetylene generated by wet process, when the latter was burned under identical conditions.

The two burners just described were subsequently mounted at equal distances from the slits of a spectrophotometer, and comparison of the brightness of each wave length of the spectrum of the two flames was made under conditions similar to those of the photometric test just described. That is to say, the two burners were compared when sup-

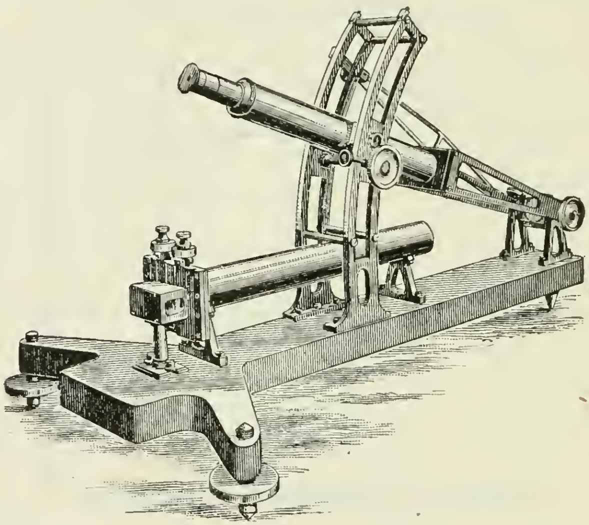

FIG. 5.—The "horizontal slit" spectrophotometer.

plied with *wet process* gas at known pressures, and this gas was then supplanted by *dry process* gas at the same pressure in the case of one of them. The results of these measurements are shown in *Fig. 4*.

The spectrometer used in these and in some of the subsequent measurements to be given in this paper was of the form described in an early volume of the *Physical Review*.* It consists, as will be seen by reference to *Fig. 5*, of a stationary horizontal collimator tube with a Vierordt slit.

* Nichols, *Physical Review*, II, 140.

This slit is placed horizontally, and the light from the two sources to be compared, which are situated at convenient distance to the right and left hand of the observer, is introduced into the collimator by means of a pair of rectangular prisms. The spectrum is produced by means of a plane grating and is viewed through an observing telescope which swings between two vertical arcs as shown in the figure. This instrument has been found to give excellent results in comparison of sources of light, the intensities of which do not vary too greatly from one another. It gives much greater dispersion in the red than any single prism instrument, and the disparity of brightness between the ends of the spectrum is less than with spectroscopes in which prisms are used.

THE FLAME OF MIXTURES OF ACETYLENE AND HYDROGEN.

It is one of the disadvantages of acetylene that unless mixed with a considerable amount of air, or of some other gas less rich in carbon, it burns with a smoky flame. While this difficulty is overcome in the ordinary types of burner employed with this gas, the necessity of mixing air in unknown proportions introduces an uncertainty which is very annoying to one seeking a source of light consisting of a standard fuel, burned under standard conditions. The mixture of acetylene with ordinary illuminating gas enables one to get rid of the use of air holes in the burner, but there is little to be said in favor of the change. Another plan which has suggested itself is the mixing of acetylene and hydrogen in given proportions, as, for example, half and half, a procedure which would admit of the complete definition of the character of the fuel. Such flames, especially where the percentage of hydrogen is large, are free from the tendency to smoke, and may be burned under conditions more readily susceptible of definition.

Dr. C. H. Sharp, in the course of some investigations made under the auspices of the American Institute of Electrical Engineers, in the search of some more suitable standard of light than we now possess, has studied the behavior of flames consisting of a mixture of acetylene and hydrogen

in equal parts when burned in oxygen. I shall refer to his results in a subsequent paragraph. Mr. Hartman* has likewise recently described measurements made upon flames of mixtures of these two gases when burned in air. He studied gases containing various quantities of acetylene (from 17 to 100 per cent.) and compared their flames with that of the pure gas.

The flames of such mixtures showed rapid increase of candle-power with increasing percentage of acetylene, to the

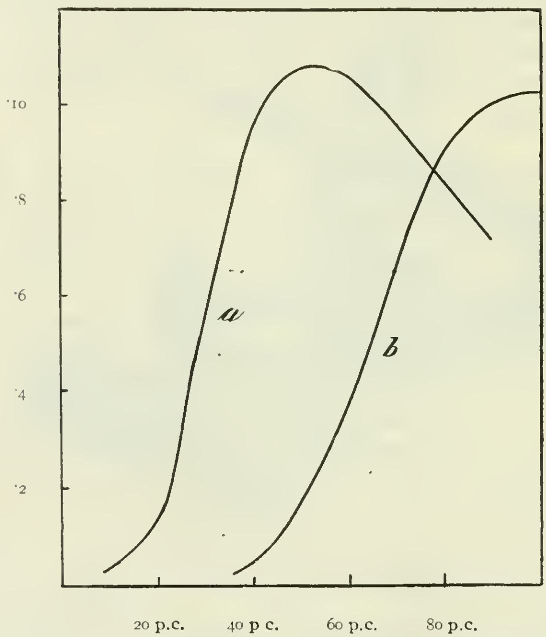

FIG. 6.—Brightness of flames (acetylene and hydrogen).

point where combustion began to be incomplete (see *Fig. 6*, curve *a*); and when burned from a small lava tip which gave complete combustion for all mixtures, the maximum of brightness, as will be seen from *Fig. 6* (curve *b*), was not reached until the gas contained 100 per cent. of acetylene.

The color of the mixed flame was found to be always whiter than that of pure acetylene. Spectrophotometric

* *Physical Review*, IX, 176.

measurements of the flames from various mixtures of acetylene and hydrogen were made, using the flame of pure acetylene as a standard. The composition of the gas in each case was determined by analysis. In *Fig. 7* two curves, illustrating the results of these comparisons, are plotted. The ordinates in each case are relative intensities in terms of that of the corresponding region in the spectrum of the acetylene flame, the brightness of both spectra in the

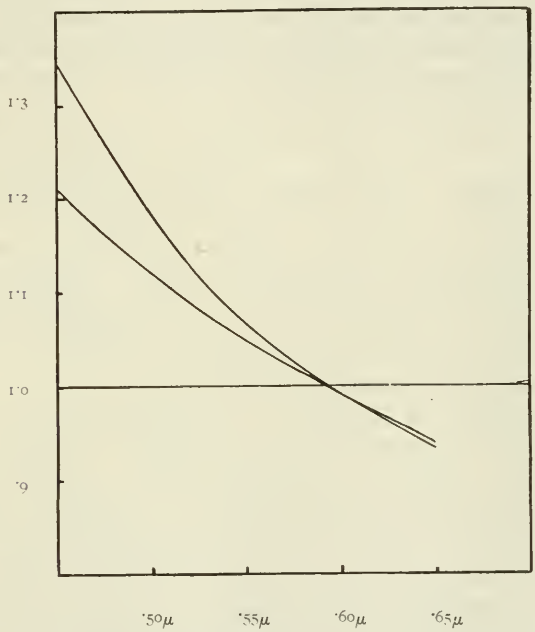

FIG. 7.—C_2H_2 and H (mixed) showing the range of color of flame (acetylene flame as unity).

region of the *D* line taken as unity. These curves have been selected from about thirty made by Mr. Hartman. They show approximately the extreme range of color in flames of mixed acetylene and hydrogen containing from 17 to 86 per cent. of the former gas. These color differences appear to be due to as yet undetermined conditions rather than to the percentage of acetylene. Some curves relating to widely different mixtures were identical, while others ob-

tained from similar mixtures were as divergent as those shown in the figure.*

The practice of using a given mixture of acetylene and hydrogen for photometric purposes would have much to recommend it but for the fact that acetylene is so rapidly absorbed by water that one can never be sure, even approximately, of the composition of such a mixture when stored for a short time over this liquid, and while the color of the flame might not be seriously interfered with by small changes in the proportions of the two components, the candle-power would vary widely with variations in the amount of acetylene present in the mixture.

SOME CHARACTERISTICS OF FLAMES OF PURE ACETYLENE.

The preliminary experiments thus far described do not, it is true, afford a very encouraging prospect to him who makes a study of acetylene with a view to its use as a standard in any sort of photometric work. The flame has, however, certain characteristics which encourage one to give it further consideration, even in spite of the serious sources of variation already pointed out.

First of these is stability, a character due in great measure to the relatively high pressures, 5, 10, 15, or even 20 centimeters, at which it is practicable to burn this gas. The degree of stability possessed by an acetylene flame of the ordinary flat form can be readily studied by throwing its enlarged image upon a screen. For such work I have found a long-bodied micro-camera of about 2 meters focal length very suitable. If the burner be set up in front of such a camera, so that the axis of the instrument is in the median plane † of the flame, the camera can be focused

* To define as precisely as possible the character of the acetylene flame used in these measurements, it was in turn compared spectrophotometrically with the flame of a Hefner lamp. The result is indicated in *Fig. 11*.

† By the median plane of a flat flame is meant the vertical plane that cuts the flame in its maximum cross-section. The axis of the flame lies in the median plane, and the latter lies midway between the luminous layers which form the boundaries of the visible portion of the flame, dividing it into equal and symmetrical parts.

upon any desired portion of the flame lying at right angles to the median plane. One then sees the flame is as if in cross-section, and can observe very accurately its structure and likewise whatever of lateral movements it may undergo. At low pressures, *i. e.*, up to 2 centimeters, the two jets of gas issuing from the orifices in the lava tip of the burner will be found to impinge upon and deflect one another, without producing any union of the two columns of heated gas. These, in point of fact, rise parallel to one another without mingling, throughout the entire length of the luminous portion of the flame. This very striking phenomenon is shown in *Fig. 8*, which is from a photograph taken of the enlarged image of a portion of the flame under these condi-

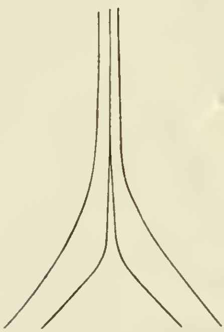

Fig. 8.

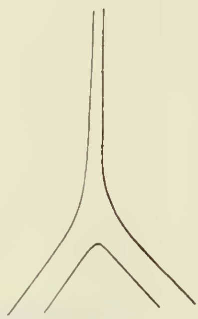

Fig. 9.

tions. Slight additions of pressure bring about complete fusion of the two jets at the point where they come into contact with one another, and the ordinary form of the acetylene flame results. The flame under these conditions is found to consist of a layer of heated gas surrounded by a sheath or mantle of highly luminous material. The thickness of the flame, measuring it through from luminous mantle to luminous mantle, is about 0·065 centimeter. The thickness of the layer itself, as can be estimated by the inspection of the enlarged image upon the ground glass of the camera, is rather less than 0·005 centimeter. *Fig. 9* is from a photograph of the central portion of such a flame as seen in the enlarged image just described. Of the extraordinary sta-

bility of the column of heated gas which constitutes the acetylene flame, I shall have occasion to offer experimental evidences in a subsequent paragraph of this paper.

Another feature of the flame which gives it importance in optical and photometric work is its great intrinsic brightness. When we consider the relatively small area of an acetylene flame as compared with that of an ordinary gas flame, the greater intrinsic brightness of the former becomes apparent. To make the matter more definite I photographed two flat flames side by side. Their areas, determined by approximate integration by means of the planimeter, were as 12 to 1. In candle-power they were equal, so

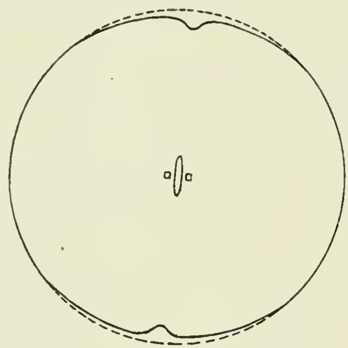

FIG. 10.—Horizontal distribution of intensity in the case of a flat flame of acetylene.

that, considering the two surfaces as homogeneous (ignoring, that is to say, the fact that each flame consists of non-luminous gas in which minute particles of intensely incandescent carbon are floating), the intrinsic brightness of the smaller (acetylene) flame was twelve times that of the ordinary gas flame.

That a flame should give twelve times the candle-power of another per unit of radiating surface implies either that the number of particles floating in the gas of the flame must be greater in that proportion, or that the temperature, or what corresponds to temperature, the degree of incandescence, is sufficiently great to account for this difference. The great brilliancy of the acetylene flame may be due to

the combination of these two causes. If the high candle-power of such a flame is to be ascribed to greater amounts of radiating material, this should indicate itself, as has been found to be the case with certain petroleum flames, by a diminished transparency as compared with the transparency of the flame of ordinary illuminating gas. This is easily tested in case of a flat flame by photometric measurements

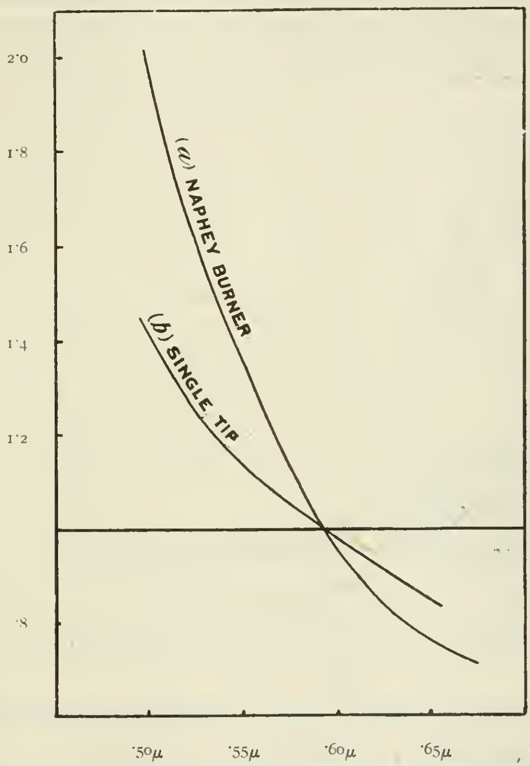

FIG. 11.—Color of acetylene flames in terms of that of the Hefner standard.

with the plane of the flame at various angles to the photometer bar.

Fig. 10 gives results of such measurements in the case of an ordinary flat flame of acetylene gas. It will be seen that the horizontal distribution is very closely a uniform one, and that the depressions in the curve corresponding to

the position in which the flame is seen edgewise are not strongly marked. It appears from the comparison of this curve with the corresponding curves obtained from a petroleum flame of the type produced by the mechanical, central-draft lamp known as the Hitchcock lamp, which furnishes a naked flame very similar in outline to the acetylene flame under investigation, and that obtained from an ordinary flat flame of illuminating gas, that the greater intrinsic brightness of the acetylene flame must be ascribed chiefly to the

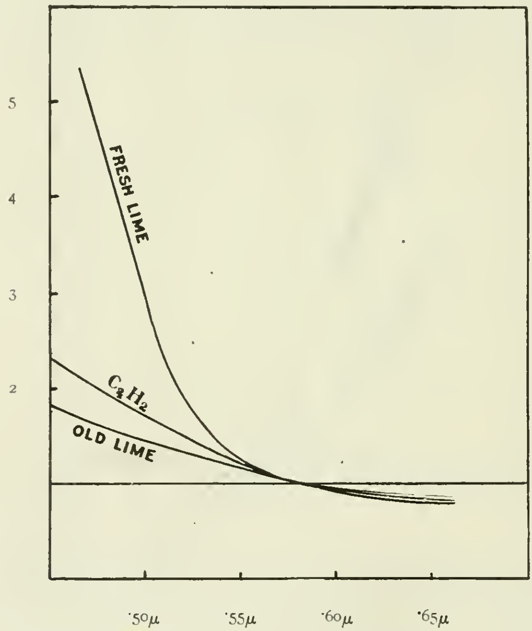

FIG. 12.—Lime-light and acetylene flame. Standard an ordinary gas flame.

high incandescence of the carbon rather than to a greater amount of radiant material within the flame. Higher incandescence, however, means a whiter color, higher temperature and higher radiant efficiency. The whiteness of the acetylene flame is a matter of common observation. To determine the color in precise terms, it is necessary to make measurements with the spectrophotometer, using as the source of comparison, the spectrum of whatever flame it is desired to contrast it with. Mr. Hartman, in the course

of his studies of flames of mixed acetylene and hydrogen, has, as I have already stated, thus compared the acetylene flame with the flame of the Hefner standard lamp. The latter is, perhaps, the most suitable flame with which to make such a comparison, since it is produced by the combustion of a fuel of fixed chemical composition under very nearly constant conditions. The results of these measurements are shown graphically in *Fig. 11*.

One of the curves (a) in this figure refers to the flame of a three-jet Naphey burner; the other (b) to a small cylindrical flame from a single tip.

The two illustrate very well the marked differences of color between flames of pure acetylene in air when burners of different type are employed, or when, for any reason, the conditions of combustion vary. *Fig. 12* contains similar curves from measurements made* some years ago upon the light of freshly ignited lime and of lime several minutes after the beginning of ignition in the oxy-hydrogen flame. The standard of comparison was the ordinary flame of illuminating gas. In this case, as in that of the previous curves, the region of the D line is taken arbitrarily as unity, and the relative intensities of other wave lengths are expressed in terms of this. The curve for an acetylene flame is introduced for convenience of comparison. In *Fig. 13* are plotted corresponding curves for the light of burning magnesium, as determined by Rogers,† for the arc light (after Vogel)‡ and for the acetylene flame, all reduced to unity at the D line and all in terms of the ordinary gas flame.

One of my students, Mr. Albert Ball, has gone a step further in the detailed study of the color of the acetylene flame. A diaphragm 1 centimeter in diameter is set up in front of the flame, thus isolating a particular region, and light from this region is compared by means of the spectro-

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* Nichols and Franklin, *American Journal of Science*, XXXVIII, 100 (1889).

† F. J. Rogers, *American Journal of Science*, XLIII, 300 (1892).

‡ H. C. Vogel, *Berliner Monatsberichte*, p. 801 (1880).

photometer with the light from an undiaphragmed acetylene flame, selected as a standard. By moving the diaphragm to different positions, the color of various portions of the flame under investigation can be separately determined. The work is still in progress, but curves already made for various regions show marked variations of color in the different parts of a single flame. The importance, to any

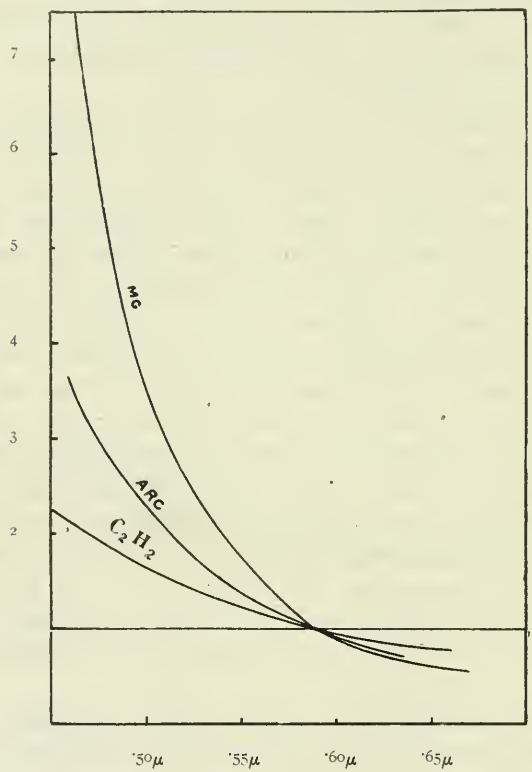

FIG. 13.—Color of magnesium light, arc light and acetylene flame. Standard an ordinary gas flame.

one who may have occasion to use a diaphragmed flame in spectrophotometry, of recognizing and correcting for the existence of such color differences is obvious.

Dr. Sharp, in the photometric investigation to which I have already referred, compared, by methods similar to the above, the color of pure acetylene burning in air, of a

mixture of acetylene (50 per cent.) and hydrogen (50 per cent.) burning in a mantle of oxygen, and of pure acetylene burning in oxygen, with the flame of a petroleum oil lamp. Curves from his measurement are shown in *Fig. 14.* Curve *a* represents measurements upon the pure acetylene in oxygen, *b* upon the acetylene-hydrogen mixture; curve *c* is for the flame of pure acetylene burning in air.

By means of the foregoing measurements and of the various determinations which I have had occasion to make from time to time in the past, on the relations between the

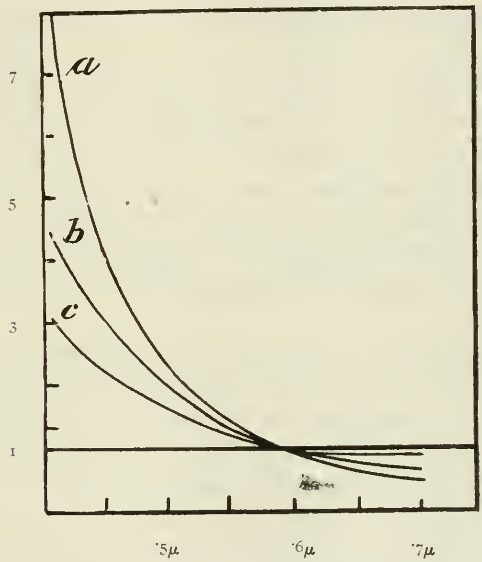

FIG. 14.—Color of flames of acetylene burning in oxygen (a), acetylene-hydrogen in oxygen (b), and acetylene in air (c).

best known artificial sources of illumination in respect to color, it is easy to assign to the acetylene flame its proper place.

As may be seen from *Figs. 12* and *13*, acetylene light is somewhat whiter than the ordinary lime light, lying between that and the light of the electric arc. The flame of acetylene burning in oxygen, which is, as has just been pointed out (*Fig. 14*), distinctly whiter than the ordinary acetylene flame, corresponds almost exactly with the light from the

carbons of a commercial arc lamp,* but falls somewhat below that from arc lamps with small carbons, such as the Foucault "regulator" tested by Vogel. The magnesium light is much stronger, relatively, in the blue than either acetylene flame or arc. Violle,† in the course of certain spectrophotometric studies, remarks that the light from acetylene gas differs but little from that of fused platinum, a statement the approximate verification of which will appear in a subsequent paragraph of the present paper.

TEMPERATURE OF THE FLAME.

Concerning the temperature of the acetylene flame, various conflicting opinions have been expressed. Le Chatelier,‡ on the one hand, has computed the temperature of combustion of acetylene and air to be in excess of 2,000°. Lewes,§ whose measurements have been much quoted, found temperatures lower than those of the ordinary gas flame, with a maximum of 1,517°. Smithells ‖ has demonstrated experimentally that the temperatures given by Lewes were too low by the very simple method of fusing platinum in the flame.

To determine such temperatures accurately by means of a thermo-electric element, it is clearly necessary to ascertain as definitely as possible the correction to be applied on account of the loss of heat through the wires of the couple. In a recent paper¶ I described measurements of flame temperatures made with a series of platinum-platinum-rhodium elements, placed successively at various carefully measured distances from the median plane of the flame. Four sizes of wire were used in the construction of these thermocouples. The temperature indicated by such junctions, when exposed to the heat of the flame, depends upon the

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* See the various data given in my early paper cited on a previous page.

† Violle, *l'Eclairage Électrique*, VI, 178 (1896).

‡ Le Chatelier, *Comptes Rendus*, CXXI, 1144 (1895).

§ Lewes, *Chemical News*, LXXI, 181 (1895).

‖ Smithells, *Journal of the Chemical Society*, LXVII, 1050 (1895).

¶ Nichols, "On the Temperature of the Acetylene Flame," American Physical Society, Feb. 24, 1900; also *Physical Review*, XI (1900).

diameter of the wire, and it is possible, by plotting curves for the variation in the indicated temperature with the cross-section of the thermo-element, to determine, approximately at least, the temperature which a junction of infinitesimal diameter would have when placed in the flame. *Fig. 15* shows a series of curves drawn for the purpose of thus estimating the temperatures of the brightest portions of an acetylene flame, a luminous flame of ordinary illuminating gas and the flame of a candle.

It will be seen that the curve for the acetylene flame cuts

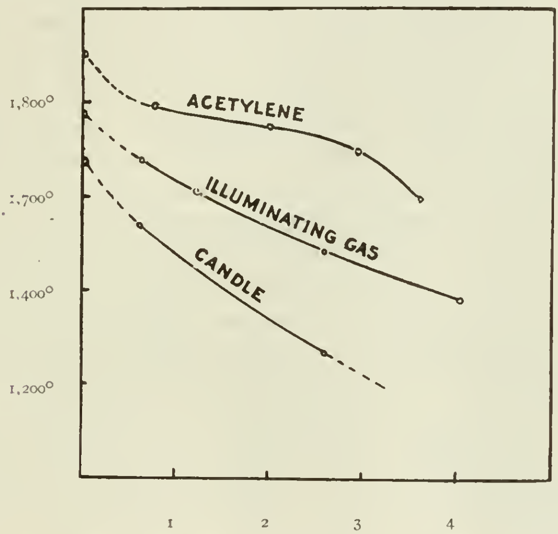

FIG. 15.—Curves plotted in the estimation of flame temperatures.

the line corresponding to zero cross-section at 1,900°. The position to which this estimate applies lies above the interior dark zone of the flame in the region which appears to the eye to be most brilliant and corresponding closely to that found by Lewes in his measurements to possess the highest temperature. Although one of the thermo-junctions employed in these measurements had a diameter of 0·008 centimeter, which is, so far as I know, the smallest ever employed in such work, the highest temperature that it reached was nearly 100° lower than that which the exten-

sion of the curve would lead us to assign to the region in which it was located.

Similar measurements upon the ordinary luminous gas flame gave a temperature of 1,780° for a region likewise situated in the brightest part of the flame. The temperatures of the luminous envelope of a candle flame showed a range from 1,675° in the brightest region to 1,450° at the tip and 1,406° at the very base of the flame. This temperature is much higher than that usually assigned to the flame of the candle by those who have attempted to measure it by means of thermo-junctions without making correction for the loss of heat carried away by conductivity through the wire. It is interesting to note, however, that it is very closely in accord with an estimate of this temperature just published by Lummer and Pringsheim.* These authors, computing by means of a relation which they have found to exist between the temperature of a radiating body and the position of the maximum of the energy curve in its spectrum, found for the candle 1,687° C. Their computation is made upon the assumption that the cooling material within the flame possesses the property of a perfectly black body. In so far as the carbon of the candle flame falls short in its radiating power of this assumption, the temperature would have to be reduced. It is probable, therefore, that their estimate is, if anything, a trifle high. It will be noted that my measurements indicate a temperature only 17° below that given by them.

It is obvious from these measurements that the superiority of the acetylene flame in the matter of intrinsic brightness and likewise in color is in greater part, at least, assignable to the high temperature which it possesses. As the temperature of an incandescent body rises, larger and larger proportions of its radiant energy take the form of waves falling within the limits of the visible spectrum. The efficiency of the source, considered as a device for the production of light, increases therefore with the temperature.

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* Verhandlungen der Deutschen Physikalischen Gesellschaft, 1899, p. 239.

Efficiency thus defined has been called by Rogers* the radiant efficiency of an incandescent body. It is the ratio of the luminous energy divided by the total energy of radiation. The only rigorous method of determining radiant efficiency consists in the determination of the curve of the distribution of energy in the spectrum for all wave lengths and a comparison of the area of that portion of the curve lying within the visible spectrum to the total area enveloped by the curve. A fair approximation can be obtained, however, by the method described by Melloni, in his classical work entitled "Thermochrose," and later developed by Tyndall, Thomsen and others. This well-known method consists in measuring the total radiation falling upon the face of a thermopile or bolometer, from the source of light under investigation and in comparing this amount with the energy which reaches the instrument when a cell containing water is interposed in the path of the rays. To determine what portion of the energy passing through the water cell is luminous, and what portion belongs to the infra-red, a cell containing a solution of iodine in carbon disulphide is likewise interposed. Although we now know that the opacity of water or of a solution of alum to the infra-red rays is by no means so complete as was assumed by the early experimenters in this field, it is found that the method will give at least a good estimate of the radiant efficiency.

Such measurements upon the acetylene flame have recently been made at my request by Messrs. Hoxie and Stewart. They used a bolometer of iron wire, between which and an acetylene flame of the usual form a cell containing a layer of water 1 centimeter in thickness with glass walls ·4 centimeter in thickness was alternately interposed and withdrawn. The ratio of the energy transmitted by the water cell to the total energy was found from thirty-nine sets of readings to be 0·207.

An iodine cell of the same size as that containing the water was subsequently interposed and readings were made from which the ratio of the energy traversing both cells to

* F. J. Rogers, *l. c.*

that traversing the water cell alone was computed. This ratio, as obtained from twenty-two sets of readings, was found to be 0·490. Upon the supposition, which is approximately although not strictly true, that the iodine cell absorbs all the visible rays capable of penetrating the water, and no others, we have for our efficiency 1·00 — 0·49 (the percentage of radiation transmitted by the water) multiplied by 0·207 (the total transmission by water). This product gives for the radiant efficiency of the flame, 10·5 per cent.

The same method applied to an ordinary flame by Messrs. Hoxie and Stewart, for the purpose of checking their results, gave 2·9 per cent. for the radiant efficiency of that source of light. These values will be found to be quite consistent with those previously obtained in the study of various sources of illumination.

Julius Thomsen* found, for example, the efficiency of a petroleum flame to be 0·02. Langley, by integration of the spectrum, obtained for the radiant efficiency of gas light (Argand burner) 0·24. Rogers,† in his paper on magnesium as a source of light, found for the magnesium flame a radiant efficiency of 0·137. Miss Crehore (Mrs. Frederick Bedell), in some studies of the lime light made under the direction of the author of the present paper (*Physical Review*, Vol. II, p. 165), found the radiant efficiency of that source to be 12 per cent. for freshly-ignited lime cylinders; falling away to 10 per cent. in the first ten minutes, and, subsequently, to values between 8 per cent. and 9 per cent. The efficiency of the electric arc varies between 5 per cent. and 16 per cent., according to the size of the carbons and other conditions. Tyndall, for example, found a radiant efficiency of 10 per cent. for the old-fashioned Foucault regulator with small carbons. Nakano‡ obtained values ranging from ·068 for carbons $\frac{8}{10}$ inch in diameter to ·16 for

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* J. Thomsen, *Poggendorff's Annalen*, XXV, 348.

† F. J. Rogers, *l. c.*

‡ Nakano, *Transactions of the American Institute of Electrical Engineers*, May 22, 1889.

a lamp with ¼-inch carbons. Reference to the set of curves showing the relative distribution of color in the spectra of these various sources, *Figs. 12* and *13*, will show that the radiant efficiency of the acetylene flame falls into its proper place with reference to the other values quoted above.

ACETYLENE IN THE LANTERN.

Quite in accordance with the foregoing measurements of the color, temperature and radiant efficiency of the acetylene flame are certain comparisons made by Miss Helen M. Latting* between acetylene and various other sources of light when used in the projecting lantern. Her measurements were made by means of the Weber photometer, with which instrument the brightness of an illuminated white screen at a fixed distance from the lantern was determined in the usual manner. The lantern was supplied successively with an alternating arc, a direct current arc with the carbons placed at an angle of 90°, a direct current arc, the carbons of which were set in the same straight line, a lime light, an acetylene burner and a petroleum lamp. The lantern used in comparing these and other sources of light was in all cases the same, and pains were taken to use those types of lamp in each case which had been found, as the result of the experience of manufacturers, to give the greatest brilliancy. The petroleum flame was from a burner with a round wick supplied with oil from a reservoir, and provided with a parabolic reflector 5 inches in diameter. The acetylene lamp also had been especially designed for use in the lantern. It consisted of four jets, placed one behind the other, with a reflector. In the case of the lime light, the brilliancy of the screen was determined as a function of the time, a method the necessity of which had been previously demonstrated in the course of the experiments of Miss Crehore, alluded to in a previous paragraph of this paper.

The following table contains a summary of the results of this comparison:

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*Helen M. Latting. Thesis in manuscript, Cornell University Library, 1899.

LIGHT FLUX FROM VARIOUS SOURCES USED IN THE LANTERN.

Source of Light.	Flux in Lumens.
Petroleum flame	3·796
Acetylene flame	20·82
Lime (freshly ignited)	56·71
Lime (old)	16·65
Arc (alternating, 550 watts)	330·00
Arc (direct), carbons parallel, 550 watts	464·80
Arc (direct), carbons at 90°, 550 watts	700·00
Arc (direct), carbons at 154½° (scissors lamp), 500 watts	921·6

It will be seen that, of the sources investigated, the electric arc is much the most powerful, and that the direct current arc is greatly superior to an alternating current arc consuming the same amount of energy. Next to the arc light comes a freshly ignited lime, then the acetylene flame, which equals approximately the brightness of a lime cylinder, if the latter has been subjected for a long time to the action of the oxy-hydrogen jet. The petroleum lamp, as might have been expected, was found to be but a feeble source as compared with even the weakest of the others.

Approximately, we may say that the acetylene burner gave five times as much light to the screen as the petroleum flame, the lime four to eight times, according to the degree of freshness, the alternating current arc ninety times, the direct current arc from 120 to 200 times the flux of the first-named source. The above-mentioned sources of light were further tested by means of the calibrated color screens furnished with the Weber photometer, and it was found that those giving the greatest total flux of light were in every case strongest, relatively, in the blue and violet.

THE ACETYLENE FLAME AS A REFERENCE STANDARD IN SPECTROPHOTOMETRY.

It is obvious, as a result of the various observations already described, that the acetylene flame, in spite of the difference due to the age and quality of the gas, is a source of light especially adapted to use with the spectrophotometer, and as a secondary standard of light in simple photometry. As a source of comparison in the study of spectra, it possesses the advantages of great intrinsic

brightness, stability, steadiness and great preponderance of rays of the shorter wave lengths. One is able, by means of such a source, to carry visual measurements much further into the extreme violet than is possible with any other sources, excepting sunlight and the light of the electric arc. Sunlight is not always at the disposal of the observer, nor is it in any sense a constant source of illumination, either as regards intensity or color. As to the electric arc, the extreme fluctuations of brightness which it exhibits totally unfit it for quantitative work in spectrophotometry. The incandescent lamp gives, it is true, a delicacy of control offered by no flame. In many operations with the spectroscope, however, the almost strictly linear character of the field presented when the collimator tube is pointed directly to the lamp itself is highly objectionable. The acetylene flame, on the other hand, presents a large surface, the intrinsic brightness of which is but little inferior to that of the filament of the incandescent lamp at normal candle-power, while it is much whiter in color than the latter. If the incandescent lamp be brought to a temperature corresponding to that of the acetylene flame, its decadence will be so rapid that the advantage already referred to, namely, delicacy of control, will be forfeited.

THE ACETYLENE FLAME AS A SOURCE OF HIGH TEMPERATURES.

The high temperature of the ordinary acetylene flame where the gas burns in air and without mechanical draft can be greatly augmented by increasing the supply of oxygen by means of a blast, or by burning the acetylene mixed with oxygen, as in the oxy-hydrogen blow-pipe. We thus get various forms of non-luminous high temperature flames, of great usefulness and convenience in the laboratory. An ordinary acetylene burner, into the supply pipe of which air under slight pressure is introduced with a proper check valve, affords an excellent substitute for the oxy-hydrogen blast lamp. In such a flame one can readily fuse quartz for the manufacture of fibers, and can melt metals of the platinum group. The ordinary flat, luminous acetylene

flame itself I have found an admirable source of high temperatures for the calibration of thermo-elements and for the determination of the melting-points of metals up to and including platinum.

This flame, as already pointed out, is of extreme stability when not subjected to drafts. From the luminous mantle

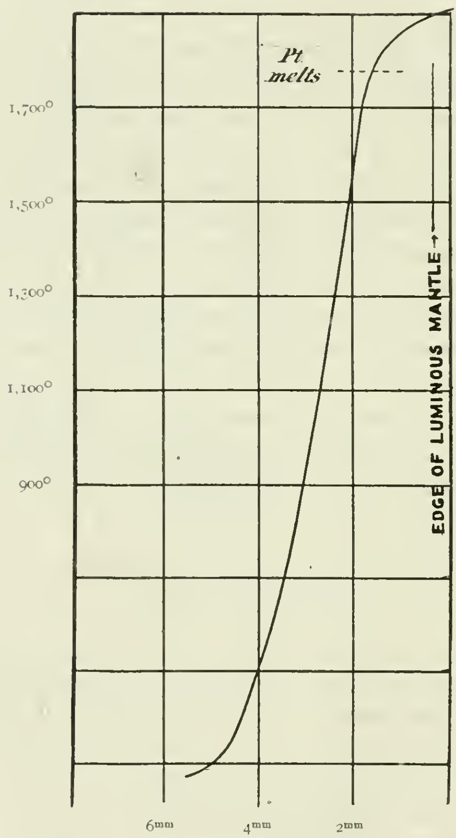

FIG. 16.—Temperature of radiant near an acetylene flame.

outward there is a very steep gradient of temperature, so that within a distance of 4 or 5 millimeters there is a range of temperature extending over more than 1,000°. The precise distribution of temperatures from the median plane of the flame outward is shown in *Fig. 16*, the data for

which are from my recent paper.* If, now, one makes a thermo-couple of platinum-platinum-rhodium (10 per cent.), the junction of which is fashioned so as to present a plane surface parallel to the median plane of the flame, and as thin as possible, and moves it toward the flame by means of a micrometer screw, it is possible to bring it to any desired temperature within the above range. So steady is the flame that, once set, such a thermo-junction will remain at this temperature with fluctuations scarcely perceptible by means of the most delicate potentiometer as long as it is kept in a fixed position. The form of junction most suitable for this purpose is that described in the paper to which reference has just been made. Such a junction is easily constructed by fusing in the oxy-hydrogen flame the two wires, platinum and platinum-rhodium, in the form of a V, and then trim-

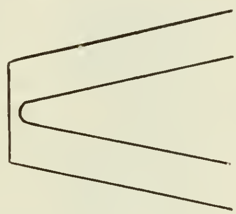

Fig. 17.—Form of thermo-junction.

ming off with a pocket scissors the apex of the V, so as to leave a very narrow link of metal. Even where the smallest wires are employed it is possible to perform the operation just described, and to produce a junction of the form shown, highly magnified, in *Fig. 17*. I have used successfully for such purposes wire of ·008 centimeter diameter, in which the link of metal left after trimming away the apex was not more than ·003 centimeter in thickness. By looping around the minute junction thus formed a tiny length of the metal, the melting-point of which is to be determined, or the melting-point of which is to afford the calibration point for the junction itself, and moving the junction with its loop carefully toward the flame until fusion takes place, a very

*Nichols, *l. c.*

exact determination of the melting-point in question can be made. The fact that the metal has begun to melt is ascertained by watching a greatly magnified image of the thermo-junction upon the ground glass screen of a micro-camera. In this way one can make a very satisfactory and exact determination of the melting-points of all such metals as are fused without serious oxidation, in the outer layers of the acetylene flame. I have applied it successfully to platinum, palladium, copper, gold and silver. In the case of metals like aluminum, on the other hand, which are readily oxidized, the method is useless. I hope at an early date to publish under separate title a detailed account of this method.

MANOMETRIC FLAMES OF ACETYLENE.

The intensely white luminous flame produced by burning acetylene within a mantle of pure oxygen, to which I have referred in a previous paragraph, has been found very useful in the photometric study of the manometric flame. The burner used in such work by Professor Merritt* and myself was devised by him some years ago in his very successful attempt to substitute photography for the slow and uncertain processes of copying the forms of the manometric flames by hand. Through a central tube of small aperture acetylene is allowed to flow, and through an annular opening surrounding this the supply of oxygen is provided. By proper adjustment of these two gases as to pressure, a conical flame of blinding brightness is produced, which has been found as delicate as the sensitive flames used by König in his celebrated experiments. *Fig. 18* shows the form of the manometric apparatus for acetylene and oxygen used by us in the study of the voice.

ACETYLENE AS A PHOTOMETRIC STANDARD.

Of the various uses of the acetylene flame, concerning which I have alluded, the most important from a practical, and possibly from a scientific, point of view is the application of acetylene as a standard of light. Its seeming fitness

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* Nichols and Merritt, *Physical Review*, VII, 93.

for this purpose has already attracted attention in various quarters, and suggestions looking toward its adoption have been made by Fessenden* and others. Experiments for the purpose of studying its application have been in progress in our laboratories at Cornell University for three years, and many of the measurements which I have described in the present paper have been undertaken with this end in view. Concerning much of this work it would be premature at the present moment to speak in any detail.

Our experience shows that the production of a primary standard which shall be reproducible in the sense that an intelligent instrument maker, by following specifications, would be able to produce an apparatus, the flame from

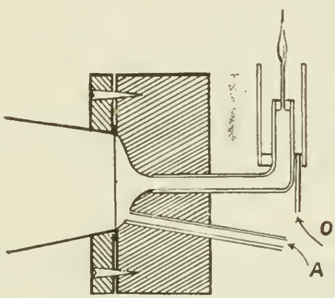

FIG. 18.—Merritt's burner.

which would in every case possess an illuminating power within the limits of accuracy of photometric processes (say 1 per cent.), is at best a very complicated matter. I have not, as yet, found an acetylene flame the candle-power of which will always be the same. A more hopeful method consists, in my mind, in determining the candle-power of a specified area of the flame, and using that as a source of light. I have indeed recently had occasion to test the constancy of the ordinary flat acetylene flame when viewed through a diaphragm of small size. During some spectrophotometric measurements I was particularly anxious to

* Fessenden, *American Institute of Electrical Engineers*, XII, p. 500 (1895).

follow the fluctuations of the flame which was used as a comparison standard. A thermopile was accordingly set up on the side of the flame opposite the slit of the instrument. Between the face of this thermopile and the flame two small diaphragms were mounted with proper screens. Radiation from the brilliant surface of the flame passed through the diaphragms and fell upon the face of the pile which was protected from all other sources of light. The thermopilé was placed in closed circuit with a delicate galvanometer, and a shutter was mounted between it and the flame in such a way that it could be opened or closed by an observer at the galvanometer. At intervals of two minutes for a period of two hours, Mr. Hartman made readings of the throw of the

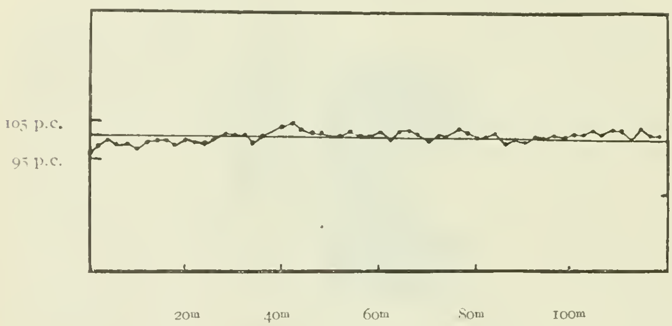

FIG. 19.—Fluctuations of an acetylene flame observed at intervals of two minutes.

galvanometer, produced by opening of the shutter during a period of time corresponding to the single vibration of the needle. The comparison of these throws gave direct indication of the fluctuations in the radiation from the flame, and from these we could deduce with sufficient accuracy the degree of constancy of its illuminating power. The results of these readings are shown in *Fig. 19*, from which it will be seen that while the flame was not perfectly constant, the fluctuations were small as compared with what one might expect from most sources of light, being fairly comparable in amount to the corresponding fluctuations found in the Hefner lamp by Sharp and Turnbull.* Using this thermo-

* Sharp and Turnbull, *Physical Review*, II, 1 (1895).

pile and galvanometer as a means of indicating brightness of the flame, I found that the radiation through this diaphragm was closely the same from day to day, and that the flame, where extinguished and relighted, returned after a few minutes' interval to its former value.

The placing of such a diaphragm in front of the present forms of the acetylene flame will, however, have to be very carefully specified. The changes in the color of the light emitted through such a diaphragm, when the latter is placed in front of different portions of the flame, as observed by Mr. Ball, have already been described. These changes of color are undoubtedly accompanied by changes in the candle-power, which would make it necessary to have the diaphragm always so placed as to expose a given region of the flame. This important precaution noted, there is, I think, much promise for the photometrician in the experiments which I have just described. There is also reason to believe that purification of the gas, such as was not undertaken for the purpose of these preliminary measurements, would further improve the conditions as to stability of color and brightness. The influence of the humidity of the air upon the acetylene flame likewise remains to be determined. These are naturally matters which one leaves to the very last in the study of a source of light. When we have secured control of the other conditions and find that our source of light is sufficiently stable to be used as a standard, the working up of these minor matters will be comparatively simple.

PHYSICAL LABORATORY OF CORNELL UNIVERSITY,
March 13, 1900.

Section of Photography and Microscopy.

Stated Meeting, held April 3, 1900.

PICTURE-MAKING IN THE DARK.

BY MARTIN I. WILBERT, PH.G.

Photography is usually understood to be the production of images by means of chemical changes in certain substances, such as silver chloride, bromide or iodide, by radiant energy. If this be the limitation of the word, much of what I wish to call attention to in this paper has nothing to do with photography, for, as I will try to prove, radiant energy, as we know or understand it, is not necessary to the production of a true image on a sensitive photographic plate.

It is well known that we are influenced by forms of energy not readily recognized by our unaided senses. For instance, many sounds are not audible to us that are readily recognized by many of the lower animals. The spectrum contains many rays outside of the portion visible to us. Scientists, from time to time, have devised many ingenious pieces of apparatus to aid in discovering, defining and differentiating these obscure forms of energy. The work done in this direction is sufficient to show that there is still a great field for research and experiment. The photographic plates provide us with means of detecting many of these elusive rays, and it is my purpose to call your attention to the ease with which many of these experiments may be carried on.

The pictures are produced inside of a box such as that used for holding dry plates. The sources of energy that may be used to produce images are as follows:

(1) Transmitted light.

(2) Phosphorescence and fluorescence.

(3) Heat.

(4) Chemical energy.

(5) Electrical energy.

(6) X-rays and kindred phenomena.

Ordinary opaque bodies are only comparatively opaque; the common cardboard, though impervious to diffused daylight, is not opaque to direct sunlight.

About four years ago, when the X-rays were first announced, many experimenters thought they discovered X-rays in sunlight.

The pictures obtained by exposing a photographic plate, properly protected, to sunlight were produced by transmitted light. These experiments may be duplicated in an interesting and instructive way by placing a sensitive photographic plate in a box, so as to have the gelatine side in contact with the bottom of the box, then placing a coin, a piece of glass and a piece of black paper on the box, bottom side up, and setting the combination in sunlight for an hour or two. On developing the plate it will be found that the sun has acted where the plate was not protected by an additional opaque substance. For instance, the piece of glass offers little or no resistance to the rays of light, differing in this respect from the X-rays, which are largely absorbed by glass.

Phosphorescence and fluorescence are phenomena that for many years have attracted little attention, but the discovery of the X-rays has revived interest in them. About fifty years ago two eminent Frenchmen, Niepce de St. Victor and Antoine Becquerel, whose fame in connection with the development of photographic processes is well recognized, made extended experiments and observations on these phenomena. St. Victor, especially, made exhaustive studies, and among his numerous contributions to the subject, the most interesting, probably, are those on "invisible phosphorescence." He discovered that many substances, while not visibly phosphorescent, would still appreciably affect sensitive silver salts. He also recorded the fact that these substances, or rather many of them, could be protected so that they would retain active properties for some time, such as a week or ten days. The protection to which he refers consists in placing the substance, after it has

been exposed to sunlight for an hour or more, in a tin box with a close-fitting lid.

There are many substances that seem to have this faculty of absorbing light and emitting it again in the dark, among them, blocks made of plaster of paris, white sugar, white, and especially glazed white, paper. Broadly speaking, we may say that any white substance will give us practically the same results. We may take advantage of this property in various ways. If we take, for instance, a print made on a piece of glazed white paper and place it in the sun for some time, then place it in the dark-room, face downward, on a photographic plate, leave it there for two or three hours, on developing the plate we obtain a fair negative. The same result may be obtained with a piece of white marble with black streaks, or a piece of china or a tile with colored figures.

Heat is a great factor in bringing about chemical changes, and it would be surprising, indeed, if it did not affect the easily decomposed active agents of photographic plates. As a matter of fact, heat contributes as much as any other source to producing fog, or spoiling photographic plates.

Heat may give, under certain conditions, a passable image of metallic objects.

If we heat a coin or a piece of metal having on its surface any design in relief and lay this on a photographic plate for a second or two, then develop the plate, we will find that we have a very fair image of the design.

Chemical action is a form of energy the possibilities of which for picture-making do not seem to have been recognized in this country. In England considerable attention has been given to the effect of chemical emanations on sensitive photographic plates. Among others, Prof. W. J. Russell, Vice-President of the Royal Society of London, has made several communications on this subject, especially an exhaustive paper published in the *Chemical News* of a recent date.*

In this paper Mr. Russell offers many suggestions for

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*See also *Science,* **11** (1900), 487.

experiments. He is the first, I think, to observe that the change produced on the surface of many metals, by oxidation in air, is such that it may be made to record itself on a photographic plate. Among the common metals that may be employed are zinc, aluminum, magnesium and copper, and their alloys. Iron seems to have a slight action under some conditions.

The requisite for success is to begin with a perfectly bright surface of metal. The easiest means of obtaining this is by scratching the surface with coarse sand-paper. If we lay the brightened piece on a sensitive plate for several hours, on developing it will be found that the metal has affected the plate to a marked extent. Substances such as glass, celluloid or thin layers of any metal do not allow of any action on the photographic plate through them, while such materials as woven fabrics or paper only intercept the action to a limited extent.

Many inorganic compounds will give results of a similar nature. I have experimented with a number, but more with a view of finding penetrating qualities similar to those developed by compounds giving us the so-called Becquerel rays, which I will mention later. Many organic compounds may be used. Among the most active are the "terpenes," chief among them being the ordinary oil (spirit) of turpentine. If we put a few drops of this oil on a piece of porous paper (blotting paper answers very well), allow all excess of moisture to evaporate and place this paper and a photographic plate together in a closed box for from five to fifteen hours, on developing the plate in the usual way it will be found that there has been a marked change. If we interpose sundry articles between the sensitive plate and the turpentined paper we will obtain an outline image of the harder and impervious articles, while the pervious or porous articles will allow the fumes to penetrate more or less, depending, of course, entirely on their thickness or porosity. Among the other terpenes that are particularly active I may mention orange, lemon and bergamot oils, any of which will act readily, in the same manner.

Speaking in a general way, I may say that any sub-

stance emitting oxidizing vapors, such as nascent oxygen from hydrogen dioxide, or any strongly odorous substance like turpentine, will effect a change in the sensitive materials of a photographic plate. It is generally admitted, I think, that the odor of a substance depends on its emitting a more or less minute quantity of a volatile principle. That this emission does not necessarily affect materially the weight of a substance is readily demonstrated in the case of musk, which will continue to give off the characteristic odor for years, without material decrease in weight.

In this connection it may be interesting to mention that odorous woods, or such as contain a resin or volatile oil, readily impress their images on a photographic plate in the dark, the active agent, of course, being the fumes or odorous vapors that are emitted by the oils or resins contained in the wood.

If we place a piece of Southern pine on a photographic plate, we will obtain, in the course of a few hours, a very good image of the grain of the wood. We may leave a piece of inodorous hardwood, such as hickory, in contact with the photographic plate for weeks without the latter being affected. Another very active agent is linseed oil. This, singularly enough, seems to increase in efficiency for some time, due, no doubt, to the fact that the process of drying is really a process of oxidation, and a comparatively slow one. This brings us to an interesting application of the phenomena. Printers' ink is, or rather is supposed to be, made up chiefly of linseed oil as a base. By taking advantage of this fact we may obtain positive images of printed matter, by simply laying a printed sheet on a photographic plate for some time and then developing the latent image.

Electricity of high potential is another source of energy acting on photographic plates through almost any protecting envelope. The effect may be accomplished with or without the actual spark.

The pictures produced without actual spark are the more interesting. If we lay a piece of metal or a coin on a plate, enclose them in a box, and then place the box in the influence of the silent discharge of an induction coil, we will, on

developing the plate, obtain what looks like a very much over-exposed negative image of the coin or piece of metal. Actual spark pictures, while interesting and sometimes quite pretty, can hardly be said to be good images.

The penetrating qualities of the X-rays are so well understood that a mere mention of them will suffice. A closely related, if not identical, series of phenomena, known as the Becquerel rays, has been attracting the attention of scientists of late. These rays seem destined to play a very important part in the development of our knowledge as to the physical properties of matter, and it is even possible that they may lead to a revolution in our theory of matter and its ultimate composition. At the present time much remains to be learned about them. We know that they are emitted by compounds of uranium, thorium and the supposed new element, polonium.

The compounds of uranium are comparatively cheap and quite active. The rays emitted have the property of traversing opaque substances, very much like the X-rays. They will affect photographic plates through an appreciable thickness of wood, cardboard, aluminum, glass, or many other substances as X-rays do. They are largely absorbed by the dense, hard substances, while the softer or thinner layers offer little or no resistance to their passage.

I should add that in making a series of experiments I have obtained decided action on photographic plates by salts of molybdenum, vanadium, cerium, bismuth, zinc and aluminum. It remains, however, to prove definitely whether this action is due to chemical emanations or to the Becquerel rays.

In conclusion, I would like to say a word as to the "spontaneous emission" of these rays. Personally, I think it would be wise to hold this assertion in abeyance, as from our present knowledge of the subject it is not at all unreasonable to suppose that some one will find a way of generating, or at least of increasing the intensity of these rays, so as to make them available, in an economic way, to take the place of the cumbersome and somewhat costly induction coil and vacuum tube.

CORRESPONDENCE.

USE OF HOT-WIRE INSTRUMENTS AS SHUNT AMMETERS.

Editor Journal Franklin Institute:

In the impression of the (New York) *Electrical Review* for September 12, 1900, there appeared a criticism of my paper on "Electrical Measuring Instruments" (published in this *Journal*, July, 1900), which is reproduced substantially herewith, viz.:

HOT-WIRE AMMETERS.— * * * "I wish to call attention to some of Mr. Stevens' remarks concerning hot-wire instruments which I think need some modification. I quote Mr. Stevens' article as follows: 'As a shunt ammeter the hot-wire instrument is a distinct failure, for, while the manufacturers claim it can be operated on ·3 volt drop for full scale, my personal experience has shown a drop of 6 volts to be necessary.' I do not know how much experience Mr. Stevens has had, evidently not as much as some other people, for hot-wire ammeters with shunts have been and are being made every day that require even less than ·3 volt drop for full scale deflection. The Stanley Electric Manufacturing Company are making hot-wire shunt ammeters from 100 ampères to 6,000 ampères capacity with an average drop of ·26 volt for full deflection. We are prepared to furnish any one wishing to purchase hot-wire shunt ammeters, from 100 ampères maximum to 6,000 ampères maximum capacity, a guaranteed fall of potential not exceeding ·3 volt.

"Again, to quote Mr. Stevens: 'It has been shown that these ammeters (hot-wire), when calibrated on direct current, are not accurate within 10 per cent. when used on alternating current unless the reactance in the shunt is exactly equal to the reactance in the instrument.' Here Mr. Stevens claims that the least possible error that the instrument can have from this cause is 10 per cent. Such a statement is manifestly absurd.

"In themselves the reactance of the shunt and the reactance of the instrument introduce no error. An error is introduced only when the ratio of the reactance voltage of the shunt to its ohmic drop is different from the ratio of the reactance voltage of the instrument and its ohmic drop.

"In the April issue of the *American Electrician*, Mr. E. A. Wagner called attention to the fact that, if the reactance voltage of the shunt was 50 per cent. of its resistance drop, and the instrument had no self-induction, then the instrument might be in error to the extent of 10 per cent. I suppose it is from this article that Mr. Stevens drew his inspiration. Mr. Wagner has since explained that he merely wished to call attention to the fact that such an instrument could be made. Of this there is no doubt, if any one wanted it. In practice, such a condition is impossible, as both shunt and instrument are a part of the same circuit, and as such have their proportionate share of the reactance.

"If the instrument and shunt are carefully designed, so that the ratios of reactance and resistance approximate each other, the error introduced becomes exceedingly small. In fact, in over 1,000 instruments calibrated on

direct current, I have never found an instrument in error when the standard shunts and leads have been used. "W. J. LLOYD.

"Pittsfield, Mass., August 21."

Replying to Mr. Lloyd's criticisms of my remarks on hot-wire instruments when used as shunt ammeters in the paper which I presented before the Franklin Institute of Philadelphia, last April, I would say that I endeavored to discuss the principal types of instruments now in commercial use without prejudice, describing as well as I could their relative advantages and disadvantages, together with their limitations, and still believe, notwithstanding Mr. Lloyd's defence of the system, that the hot-wire instrument does not meet the requirements of modern shunt ammeters.

For Mr. Lloyd's information I would say that the hot-wire instruments which I have tested were not manufactured by the Stanley Electrical Instrument Company, but by a foreign corporation; they were, however, as nearly as possible identical in construction with those of the Stanley Company. Every essential part seems to be the same, the only difference being that the Stanley Company has slightly Americanized some few parts. The manufacturers of the instruments tested by me made the same claim as the Stanley Company, and the figures I submitted were from actual test, namely, a drop of 6 volts to obtain full scale. I am, however, quite willing to accept Mr. Lloyd's figures as representing the present practice of his company (in fact, I gave them in the article referred to), but would call attention to the fact that a drop of ·3 volt is excessive in any shunt ammeter.

The D'Arsonval instrument is to-day the standard and accepted type of shunt ammeter for direct current circuits, and D'Arsonval instruments are constructed every day to operate on a drop of ·03 volt or less. This is just one-tenth the energy required in Mr. Lloyd's hot-wire instrument. To show this difference in figures, assume a circuit of 5,000 ampères. The hot-wire ammeter requires a drop of ·3 volt, or a total of 1,500 watts to operate it; while the D'Arsonval ammeter requires only ·03 volt drop, or a total of 150 watts. The difference between the two is 1,350 watts or 1·8 horse-power at the switchboard. Professor Marks, in a recent article entitled "Commercial Electrical Measurements and Prices," gives the cost of 1 horse-power per year in a large, well-equipped station as $59.50, which, less his allowance of 15 per cent. profit, amounts to $50.49. From this it follows that the surplus horse-power required to operate a hot-wire shunt ammeter, as against a D'Arsonval shunt ammeter, costs the station $90 per year for every 5,000 ampères output. This $90 per year represents (at 6 per cent.) a capitalization of $1,500, so it follows that the central station could afford to pay, if necessary (but it is not), $1,500 more for D'Arsonval shunt ammeters to indicate 5,000 ampères than for corresponding ranges of hot-wire shunt ammeters.

I did not feel justified in giving so much detail in my original article, but I feel that the figures submitted above justify my statement that "as a shunt ammeter the hot-wire instrument is a distinct failure."

Touching on the use of the hot-wire shunt ammeter for alternating current measurements, the power consumption remains the same as in direct current measurements, and, as the cost of power production is practically the same, the figures given above will apply. As to the variations in indications when

such an instrument is calibrated on direct current and used on alternating current, I would say that my personal experience has shown 10 per cent. to be a fair average difference. I have not tested 1,000 instruments, but the few I have tested have shown very considerable divergence, particularly on high frequencies in inductive circuits. I am, however, open to conviction on this point when any impartial observer submits actual figures obtained under commercial conditions.

Since it is nearly always possible to measure alternating current output on the primary side of the line, where the current to be measured is small, I do not see the advantage of a shunt ammeter as compared to a series ammeter which can be calibrated directly at the frequency employed and made absolutely accurate. Where the current exceeds 1,500 ampères a series transformer may be employed.

I presume, since Mr. Lloyd does not combat them, that the remainder of my remarks on hot-wire instruments, such as heating errors (a matter of considerable moment in shunt ammeters), tendency to burn out on overloads, and low resistance of voltmeters, are allowed to pass unchallenged. If I am in error on any of the above points I am ready to be corrected at any time.

J. FRANKLIN STEVENS.

PHILADELPHIA, September 8, 1900.

Franklin Institute.

[*Proceedings of the stated meeting held Wednesday, October 17, 1900.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 17, 1900.

President JOHN BIRKINBINE in the chair.

Present, 142 members and visitors.

Additions to membership since last report, 22.

The meeting was devoted to the reception of the reports of the delegates appointed to represent the Institute at the Paris Exposition.

Mr. Carl Hering introduced the subject by a general account of the exhibition, illustrating his remarks by showing a series of lantern views, embracing a plan and bird's-eye views, pictures showing the grouping of the various buildings and their surroundings, and of a number of the more important single buildings. He followed this general introduction by an account of the electrical features of the exhibition.

Mr. W. C. L. Eglin supplemented the previous speaker's remarks by calling attention to a number of the specially interesting electrical exhibits.

Dr. Jos. W. Richards referred in some remarks to the electro-metallurgical exhibits, especially to the aluminum industries, and to the interesting development of the gas engine for the generation of power from the waste gases of blast furnaces.

Mr. A. M. Greene, Jr., gave special attention to the mechanical and engineering exhibits, illustrating his remarks with the aid of a number of lantern views.

The meeting thereupon adjourned.

WM. H. WAHL, *Secretary.*

COMMITTEE ON SCIENCE AND THE ARTS.

[*Abstract of proceedings of the stated meeting held Friday, October 12, 1900.*]

MR. H. R. HEYL in the chair.

The following reports were adopted :

(No. 2062.) *Process for Making Artificial Graphite.*—E. G. Acheson, Niagara Falls, N. Y.

ABSTRACT.—This application covers the production of artificial graphite by the electro-thermic method, and is the subject of several letters-patent of the United States (1895 to 1900).

The earliest procedure (United States patent No. 542,982, July 23, 1895) relates to the production of pure electric light carbon by subjecting impure carbon to a high temperature for a sufficient length of time to volatilize its impurities.

The next procedure is set forth in United States patent No. 658,323, September 29, 1896, and discloses a new principle in the art, namely, that "in the conversion, by simple heating, of carbon into graphite, the yield of graphite is greatly increased when the carbon used in the operation contains a considerable proportion of mineral matter." The inventor made the observation that the purest carbon would not turn into graphite by prolonged heating alone, but that the conversion was immediate if it was first mixed with mineral matter, such as metallic oxide. On this observation he founded the theory that the mineral matter first formed carbide by combining with carbon present, which carbide was subsequently dissociated at higher temperatures into metallic vapor and graphitic carbon.

This theory the committee believes to be a correct inference from the facts observed.

The latest patent considered, No. 645,285, March 13, 1900, relates to an extension of that above referred to.

It is based on the observation that, given two kinds of impure carbon, containing the same quantity of mineral matter, that one is most completely converted into graphite in which the mineral matter is most uniformly distributed. Thus, coke and charcoal made from resinous woods are very irregularly converted, while charcoal of non-resinous woods, and especially anthracite coal, in which the ash is very uniformly distributed, undergo practically complete graphitization. The process described in this patent is accordingly based on the selection for graphitization of those natural carbonaceous materials in which the mineral matter is most uniformly distributed.

The report concludes that "Acheson's patents, taken together, throw much light on the scientific question of the production of graphite. Their application has been immediate and energetic, and bids fair to form the basis of an important industry. The fact that the company exploiting them has already exported large quantities of its product to Europe speaks much for the superiority of the process and its results." The award of the John Scott Premium and Medal is recommended. [*Sub-Committee.*—Samuel P. Sadtler, Chairman ; Jos. W. Richards, Carl Hering.]

(No. 2099.) *The Arithmachine.*—The International Arithmachine Company, Chicago.

ABSTRACT.—This invention, which is an exceedingly compact form of calculating machine, is the subject of United States Letters-Patent No. 617,094, January 3, 1899, and No. 624,788, May 9, 1899, issued to Henry Goldman. For the mechanical details of the device reference must be made to the patents.

The report states that the operation of the machine can be learned without difficulty. It can be used advantageously only for adding and subtracting, and has therefore only a limited application, but under some conditions it may be very useful. The machine exhibits not only the ingenuity but also the skill of the inventor as a maker of fine machinery. The workmanship is excellent in every respect.

The report makes the grant of the Edward Longstreth Medal of Merit to the inventor. [*Sub-Committee.*—Hugo Bilgram, Chairman; George S. Cullen.]

(No. 2109.) *Automatic Screw and Metal-working Machine.*—Acme Screw Company, Hartford, Conn. (Referred by the Bureau of Awards of the National Export Exposition.)

ABSTRACT.—This invention, in the judgment of the investigating committee, marks a radical progressive departure in automatic machines for making screws and other work of similar character. The principal innovation consists in supplying a multiple of spindles, each holding a bar of the stock and bringing them successively in working contact with the various tools. For details, reference must be made to letters-patent filed with application.

The report concludes as follows: "The details of the machine are carefully designed. The construction of the clutches by which the driving gear-wheel is secured to the four spindles is very ingenious and specially designed for the purpose.

"By simultaneously subjecting four rods of the material to the various operations, the machine will turn out the work practically four times as rapidly as is possible where the tools are placed in a turret and successively brought to register with a single rod, as has been done heretofore in automatic screw machines. The award of the John Scott Legacy Medal and Premium is recommended." [*Sub-Committee.*—Hugo Bilgram, Geo. S. Cullen, Wilfred Lewis.]

[*To be concluded.*]

SECTIONS.

SECTION OF PHOTOGRAPHY AND MICROSCOPY.—*Stated Meeting*, held Thursday, October 4th. Dr. Henry Leffmann in the chair.

Mr. John Bartlett, of Philadelphia, presented the paper of the evening on "Photographic Sophistications," which he illustrated by a number of cleverly deceptive photographs. Following is an abstract of Mr. Bartlett's remarks:

"Within the last few years photography has held whatever art status it possesses by fee simple of its faithful representation of nature in whatever phase she is presented to us by methods peculiar to photography and not by artistic dodges or devices.

"Painting has its peculiar legitimate methods, which may justly be accorded it, because of necessity the painter must have recourse to all sorts of tricks to cheat the imagination, to convey through the physical vision to the mental vision the individual impression of an object or scene in nature.

"The 'faking' or dodging which painting must make use of is resorted to not because the painter despises to give an actual transcript of the harmonious coloring of nature, but by reason of the limitation of the means at his command. Painting suggests nature, and is consistent in her treatment, but in suggesting often is compelled to give a color or a form which is not an actual embodiment of the thing itself.

"The recent artistic movement in photography, which has been called by its advocates the impressionalistic school, by its opponents the fuzzy or blotesque, doubtless has opened a new field for æsthetic photography; but, like all radical movements, it has been pushed too far, and has therefore subjected its votaries to the charge of sensationalism and effectism. But sensationalism has always been regarded as a step downward in art, since it tempts, by its very demands of dash and coarseness of execution, to carelessness of manipulation and disregard of technique.

"I have chosen the title 'photographic sophistication' because sophistication may be defined as that which gives the impression of truth and reality by means of that which is false or unreal. I have endeavored by means of photographic illustrations upon the screen to show that such a sophisticated method of photography might be accounted legitimate in accordance with the dictum of the modern impressionalistic school. I have sought to cheat the vision by presentation of apparent natural landscapes by the employment of combinations of things which have no lot or portion in the actual scenes of nature. I have called into requisition such incongruities as a bar of soap, old corks, coal, ashes, pieces of cinder, old rags, clippings of celluloid, stones, moss, hair, twigs, in fact 'any old thing,' and have endeavored to build up therewith the simulation of a landscape composition.

"The endeavor was begun in a mere spirit of mischief, as a sort of burlesque show on legitimate art photography; but I builded better than I knew, and trust that I have demonstrated the validity of my claim, that if '*faking*' of negative and print is admissible to produce the so-called pleasurable effect, why not 'faking' of the original scene itself."

Mr. F. E. Ives showed a photograph which had been made by exposing in the camera a card coated with luminous paint, then removing it to the dark room and placing it in contact with a photographic sensitive plate, which was afterwards developed in the usual way.

In reply to a question, he said that he believed the luminous paint card, if it had been kept in total darkness for several days, need not be exposed in the camera very much longer than would be necessary for a photographic sensitive plate, provided that it was exposed with a large aperture lens and the object illuminated by sunlight, and the card *immediately* removed to the dark room and pressed in contact with the sensitive plate for several hours. If the card was exposed in the camera for a few seconds under the conditions he had named, it need not remain in contact with the photographic plate for more than two or three seconds.

He also showed a photograph which had been obtained in total darkness

by the action of reflected heat rays, which were made to form an image of the object by means of a rock-salt lens. The object was a polished metal key check, exposed to the rays of a lime-light, from which the visible rays had been absorbed by a screen. The best screen for this purpose was a sheet of vulcanite. The luminous paint card was first exposed to daylight, to make it evenly luminous, and then to the invisible image, which produced a dark image upon the luminous surface by exhausting the luminosity. The card was then placed in contact with a photographic plate for a few seconds, and the plate was afterwards developed, as in the first experiment. So far as he knew, this was the only photograph of an object ever made by reflected heat rays, made to form an image in the camera. He had shown the same photographs several years ago, but thought that they would be new to some of the members present.

Both communications were freely discussed.

Adjourned. F. M. SAWYER,
Secretary.

MINING AND METALLURGICAL SECTION.—*Stated Meeting*, held Wednesday, October 10, 1900. Mr. Joseph Richards, President, in the chair.

The meeting was devoted to the further discussion of the subject of Mr. Paul Kreuzpointner's paper entitled "Riddles Wrought in Iron and Steel." The attention of the meeting was specially taken up with Mr. A. E. Outerbridge's contribution to the subject, entitled "The Physics and Chemistry of Cast Iron," and the discussion of the same by Dr. Henry M. Howe, Messrs. W. R. Webster and Asa W. Whitney, which had been put in type and circulated in advance. Mr. Kreuzpointner opened the discussion and was followed by Messrs Outerbridge, Webster, Whitney and others. (Reserved for publication in full.) G. H. CLAMER,
Secretary.

MECHANICAL AND ENGINEERING SECTION.—*Stated Meeting*, held Thursday, October 11, 1900. Mr. W. F. Rowland, Jr., President, in the chair.

The subject for discussion announced on the program was "The Economical Operation and Maintenance of Steam Boilers." Opened by Prof. H. W. Spangler. (An abstract of this communication will shortly appear in the *Journal.*) The discussion was participated in by Messrs. J. L. Gill, Jr., Spencer Fullerton, the presiding officer, and others.

DANIEL EPPELSHEIMER, JR.,
Secretary.

ELECTRICAL SECTION.—*Stated Meeting*, held Thursday, October 18, 1900. Prof. W. S. Franklin, President, in the chair. Present, twenty-six members.

The meeting was devoted to the presentation of reports from the delegates of the Institute to the Paris Exposition.

Communications on the more interesting and important items of the electrical portion of the Exhibition were made by Messrs. Carl Hering and W. C. L. Eglin. The speakers illustrated their remarks with the aid of a number of lantern views.

The communications were discussed by Chairman Franklin, Mr. E. A. Scott and others.

RICHARD L. BINDER,
Secretary.

JOURNAL

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THE ROUND-LAP BALE SYSTEM FOR BALING COTTON.

[*Being the report of the Franklin Institute, through its Committee on Science and the Arts, on the System of Baling Cotton employed by the American Cotton Company. Referred by the Bureau of Awards of the National Export Exposition. Sub-Committee.—Chas. E. Ronaldson, Chairman; James Christie, M. R. Mucklé, Jr., Chas. A. Teal.*]

HALL OF THE FRANKLIN INSTITUTE,
[No. 2118.] PHILADELPHIA, March 1, 1900.

The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the merits of the American Cotton Company's Round-Lap Bale System, reports as follows:

After a close and careful examination of some detail drawings furnished, your committee has gained a fairly clear understanding of the machine and its product known as round-lap bale cotton. This double press lays up and bales only cotton.

The process may be described concisely as follows:

The cotton, in flakes, as it comes from the gin, is fed up the lint flue (where considerable dust settles in the dust bins in the bottom of this flue) to the condenser (revolving at about fifty turns per minute). At the condenser the remaining dust and dirt are eliminated and carried off through the dust flue overhead. The flakes hold to the cylinder of the condenser but a moment, falling into the bat former, where they are assembled into a smooth, regular-running "bat," which, coming down from the bat former, passes under the compression roll, which compresses the bat only enough to expel the air. Thence it runs down and around the core-shaft, by means of the baling belt, and is wound up, lap around lap, until several layers are run upon the core-shaft, when the baling rolls come into play and the increasing bale moves the movable rolls (attached to the hydraulic pump) back, thus forcing the pump plunger into the cylinder, driving the water up into the air chamber, compressing the air and increasing the pressure. This pressure increases until the bale is about one-third in size, when the maximum pressure is reached and maintained (by means of a relief valve) to the finish of the bale. As the bale nears completion, a bell signals the fact, when the operator throws over the tilting board, which diverts the bat into the other press and a new bale is started. The press holding the bale just completed is stopped; a fine, close-woven burlap is run into position, press started, and burlap wound around the bale till it overlaps. It is then cut to proper length to receive the ends, which are sewn in after the bale has been taken from the press. The air during compression is excluded, not forced out, as is done in compressing a square bale; the fiber is not twisted, and any possibility of destruction of fiber is eliminated; its elasticity remains intact. The fiber remains quiescent upon unrolling a bale, and if there be any expansion, it is very slight, and in the direction of the thickness of the bat and not laterally, indicating that the fibers are not tangled, but lie about parallel to one another. The baling belts are the width of the rolls, and are kept taut by properly-arranged tension rolls.

This round-lap bale is especially worthy of notice, as it presents features possessed by no other bale in the market: that wherever it is to be used, each and every bale can be unrolled clear to the center; also, these bales, as they are unwrapped, can be fed to the lappers without extra hand labor; also that several bales can be unrolled and fed into the lapper at the same time, thus mixing automatically.

Therefore your committee would respectfully call attention to the several points of merit in the double press itself, notably:

(1) The bat former and the method pursued in excluding the air from the cotton while in it, or passing through it to the compression rolls.

(2) The arrangement of rolls to produce the necessary compression upon the bale, whereby the operation of the machine becomes continuous—the device used in encasing the finished bales, in close-woven burlaps.

(3) We would particularly call attention to the round-lap bale, the product of this double press, inasmuch as it is unique. It is simply a continuous roll of cotton, of uniform width, wound under pressure, and, when properly encased, requires no further care, no ties, etc., has a greater uniform density than the square bale of commerce, and far less liability to damage by fire or water, or from any source in transit. It is more convenient to handle, and extremely economical of space. The danger of tampering with the round bales, or of fraudulent practices upon it, are reduced to a minimum, while, when it is used in the mill or factory, a very considerable amount of hand-labor, and consequently expense, is saved.

From a great mass of evidence which the sub-committee has gathered it appears that the round-lap bale system introduced by the American Cotton Company has positively done away with all the objectionable features of the old style " square bale " method of baling cotton, against which the cotton spinners of Europe and America have been protesting for many years most emphatically, and, incidentally, that the new system introduced large economies, the benefits of which are enjoyed by producers and factors, as well as by

the spinners. These economies are conservatively estimated as equivalent to many millions of dollars on the yearly cotton crop, due to the great increase of the commercial importance of the improved system of baling introduced by the American Cotton Company. The highest award in the gift of the Institute is believed to be only a proper recognition of the importance of the revolution in the cotton industry brought about by the introduction of the round-lap bale system, and the award of the Elliott Cresson Medal is accordingly made by the Franklin Institute to the American Cotton Company, of New York.

Furthermore, while the investigation of the sub-committee has been confined nominally to the consideration of the merits of the round-lap bale produced by this company, the investigators deem it proper to embrace in their report a reference to the machine or compress by which the production of this form of baling is made practicable, and without which the system could not have been made technically and commercially successful. The machine in question is admirably adapted for its intended purpose, and it appears to the investigating committee to be eminently proper to emphasize its interest commensurate with the successful operation of the round-lap baling system by some recognition. Accordingly, the award of the John Scott Legacy Premium and Medal is recommended by the Franklin Institute to Magnus Swenson, of Chicago, Ill., for his round-lap baling cotton compress.

Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, April 4, 1900.

JOHN BIRKINBINE, *President.*
WM. H. WAHL, *Secretary.*

Countersigned by
H. R. HEYL,
Chairman of the Committee on Science and the Arts.

APPENDIX.

In tracing the history of the round-lap system of baling cotton, the earliest invention distinctly describing a "cylindrical bale" was that of Wm. B. North, of Jersey City, N. J.

(see U. S. patent No. 5,632, of June 13, 1848). This invention described an improvement in cotton presses, the essential features of which consisted of a combination of three rollers so arranged that a line joining their axes would form an equilateral triangle, and which were suspended and weighted in such manner as to be capable of moving apart as the cotton fed between them from the gin accumulated in the form of a round bale. This patent of North may be regarded as the basic patent on the round-lap baling system for cotton.

This invention appears to have attracted no attention, and nothing in this direction appears to have been accomplished of any practical value until the year 1885. In that year, and those closely following, came the inventions of T. M. Workman (No. 331,932, December 8, 1885), H. A. Evans (No. 366,943, July 19, 1887), J. W. Brown (No. 446,128, February 10, 1891), P. L. & W. Brady (No. 378,570, February 28, 1888), J. W. Graves (No. 510,383, 6 and 8, December 5, 1893). None of the inventions here enumerated seems to have found commercial application. Following these came the inventions of W. T. Bessonette, of Temple, Tex., bearing dates as follows: Nos. 492,132, February 21, 1893; 508,909, November 21, 1893, and 541,418, June 18, 1895. These inventions are specially mentioned at this place because it has been claimed that they embody all the essential features of the modern round-lap baling press now commercially used. Investigation shows that the last-mentioned invention of Bessonette is the only one which possesses any similarity to the modern lap-bale press. This patent is for an invention describing a two-roll horizontal press, with three belts extending over only one of the rolls. The records of the Patent Office show that Mr. Bessonette was not the inventor of the horizontal press, so that his only claim to novelty in the patent in question resides in the employment of a plurality of endless belts extending over one of the rolls for the purpose of shaping the bale. This arrangement of parts of a press is entirely impracticable, and, so far as the committee is aware, the press of Bessonette never came into commercial use.

The only presses, of which the committee has knowledge, now commercially used are those of George A. Lowry, of Boston, Mass., and Magnus Swenson, of Chicago, Ill.

THE WELSBACH LIGHT.

[*Being the report of the Franklin Institute, through its Committee on Science and the Arts, on the exhibit of the Welsbach Light Company, of Gloucester City, N. J., referred by the Bureau of Awards of the National Export Exposition. Sub-Committee.—Arthur J. Rowland, Chairman ; C. A. Hexamer, Wm. McDevitt, Frank P. Brown, Moses G. Wilder.*]

HALL OF THE FRANKLIN INSTITUTE,
[No. 2130.] PHILADELPHIA, May 2, 1900.

The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the merits of the Welsbach Light, which was referred to the Committee by the Jury of Awards of the late National Export Exposition, 1899, reports as follows:

The procuring of artificial light by some means other than using the flame of burning carbonaceous material in the ordinary candle, lamp or gas burner, has been the aim of many investigators. As a result of this endeavor, we find on the one hand lamps in which carbon is heated to a point where it gives off light—or becomes incandescent—as by the passage of an electric current through an incandescent filament or arc lamp crater; or, on the other hand, lamps in which the incandescence of certain substances (oxides of certain of the elements for the most part) is produced by the application of a heating flame or the passage of an electric current to raise their temperature. Of these latter burners, the development of those using a heating flame applied to produce incandescence of rare earths is the particular thing dealt with in this report, but it seems impossible to avoid a mention of others when giving an outline of the chain of discoveries and inventions leading up to the Welsbach light of to-day.

It is probable that Drummond is one of the earliest discoverers of the fact that heated oxides of certain elements incandesce. Certainly he made the first practical application of the fact. Every one knows of the Drummond or lime light which has been so commonly used in the projection lantern. A piece of lime, or better, a piece of oxide of magnesium, or, most refractory of all, a piece of oxide of zirconium, has an oxyhydrogen flame play upon it and is thereby heated to a temperature at which it incandesces and gives off an intensely-bright white light. Lieutenant Thomas Drummond, in the English government service, made this discovery in 1826, and used it in connection with his heliostat in surveying work, and afterwards proposed the same arrangement for lighthouse service.

In 1868, Le Roux, Professor at École Polytechnique, Paris, discovered that a brilliant incandescent light might be procured from a rod of lime or magnesia, by heating it until an electric current passes, this afterward maintaining the light.

In 1879, Jablochkoff patented the use of a piece of kaolin as a source of light, making it incandesce by passing an electric current through it. He had noticed that the kaolin he had placed between the carbons of his arc lamp assisted the illumination.

These inventions show something of the development of knowledge regarding materials which might be made incandescent, and the means taken to make them incandesce.

Several years later, in 1881, W. M. Jackson (an American) invented the device of a lamp made of platinum, iridium or other materials non-oxidizable at high temperatures, in the form of wires of small section which were heated to incandescence by the use of a heating flame. He discovered that the finer his wires, the more intense the light produced. Here is a beginning of a mantle light.

In 1881, Charles M. Lungren, of New York, patented in the U. S. Patent Office an improvement in illuminating apparatus, which consisted in passing a non-luminous gas flame through a heater of clay or similar material highly

heated by jets of the non-luminous gas, and forcing atmospheric air through the heater and causing it to mingle with the non-luminous gas issuing in one or more jet flames against lime, magnesia, zirconia or similar material, producing incandescence.

In the same year (1881) Mr. Lungren filed an application in the Patent Office for a means of illumination which consisted in forming a filamentary body of refractory material, said body having the structural form necessary to envelope a gas flame and to be rendered incandescent by such flame.

This application, after allowance by the Patent Office, was permitted to lapse, and no patent was then issued.

Mr. Lungren, however, renewed his application in August, 1885, and the patent, which embodied improvements upon his unissued patent of 1881, was issued July 5, 1887 (No. 365,832). Subsequently, a second patent (No. 367,534), describing specific features of his incandescent lighting method, was issued to Lungren under date of August 2, 1887.

In the first of these patents Lungren describes his method of making refractory filaments for lighting composed of "lime, magnesia, zirconia, etc.," by preparing a plastic mass of these materials, or mixtures of them by kneading them with water, or preferably, a solution of a mucilaginous binding material, such as glue or gum, or other combustible material which will be consumed in the further treatment of the filament. When the mass is of the proper consistence, it is put in a press and the filament is obtained by expressing the material through a die. Immediately after their formation, and while still moist, the filaments are formed up into various shapes desired by bending or coiling over a mandrel of wood coated with plumbago, or other device, and then dried, when they are ready to apply to a support and to be used in connection with a gas flame, in substantially the same manner as the well-known Welsbach mantle.

The Lungren incandescent lighting system was the subject of investigation by the Committee on Science and the Arts of the Franklin Institute in 1891. Prolonged practical

tests of the Lungren filaments showed that they possessed unusual life duration in service, with satisfactory lighting quality, and the award of the John Scott Legacy Premium and Medal was made to the inventor.

For reasons unknown to your committee, this promising invention was never commercially exploited.

The next year (1882) a Frenchman, Charles Clamond, invented a lime light operated without oxyhydrogen flame by intensely heating the air used and directing the flame of his air and gas mixture against the refractory oxide chosen. He knew of the possible use of certain other metallic oxides to produce an incandescent light, and even invented a basket or mantle of magnesia threads, supported in an enclosing platinum mantle of small wire and large mesh, which was hung below the lamp and the heating flame directed down into it. The threads were made from magnesia which was calcined and pulverized, then made plastic by mixing with salts of magnesia, which may be afterwards decomposed by heat, then squirted through a die, woven into a basket form and dried and baked.

In 1885, Otto B. Fahnehjelm, a Swedish inventor, secured an American patent (see U. S. Patent No. 312,452, February 17, 1885) for an incandescent light which consisted in the combination with a suitable gas burner and a shade holder of means for suspending an incandescent body in the flame of the burner, and for adjusting the incandescing body horizontally and vertically in relation to the flame. The Fahnehjelm light consisted substantially of a series of rods of calcined magnesia, resembling the teeth of a comb, held in a suitable frame and suspended in a non-luminous flame of gas.

In 1886, Galopin and Evans (in Australia) produced a lamp burning hydrocarbon vapor mixed with air to produce a heating flame, directed downwards into a woven platinum mantle, which was thus made incandescent.

About this same time, or even a little earlier (1885), Carl Auer von Welsbach announced the invention of a lamp in which the rare oxides of lanthanum, yttrium, zirconium, etc., in a finely divided condition, were rendered incandes-

cent by heating to a high temperature. The source of light was a light network of cotton thread impregnated with a solution of the salts of the combined nitrates, oxides or bromides. After being saturated with these, upon exposure to heat, the supporting cotton network was burned out, the salts converted into the oxides and a skeleton hood or cap thus prepared, which would incandesce when a heating flame was applied to it.

The absolute originality of this form of mantle and method of manufacture should be carefully noted.

The nitrates of the metals, being very soluble, were especially adapted to the process, although sulphates, iodides or bromides could also be used.

Welsbach found that this mantle, as it came to be called almost from the first, could resist the action of all atmospheric air fit to breathe for an indefinite length of time, was not changed by exposure and would remain effective for a long time.

For the next five years or more von Welsbach was constantly at work making elaborate investigation of the properties of all oxides of metals which would incandesce when used separately, and when combined in various mixtures. He invented processes whereby the salts of the metals required for impregnating mantles might be prepared from the natural ores, originated means for strengthening the frail mantle, arranged the mantles for transportation in safety, and perfected many details making the lamp practical.

It is interesting to notice that the form of mantle and the general process of manufacture have remained up to the present precisely as von Welsbach originally planned them, without improvements or essential modification of any kind.

One or two of the discoveries of von Welsbach are necessarily mentioned a little in detail, to explain the magnitude of the investigations he conducted and the sort of results he procured.

A patent No. 409,531, August 20, 1889, explains that the illuminating power is greatly increased by adding thorium

oxide; that lanthanum oxide without sufficient thorium oxide crumbles when incandescent—with it the mantle becomes flexible. Later he found (patent No. 563,524) that thorium oxide, by the addition of a small per cent. of uranium or cerium oxide, has a very high illuminating power, producing a vivid and nearly white incandescent light, in spite of the fact that thorium oxide alone radiates little light which is yellow in color, and that uranium oxide alone radiates little light, and it is yellow reddish. Still later, he discovered that the illuminating power of lanthanum, cerium, yttrium, zirconium and other metals of the refractory earths is greatly increased by the addition of thorium oxide (ThO_2); that cerium not only gives a yellow light (very desirable color), but greatly increases the life of the mantle, causes it to hold its shape better, and makes it in every way stronger and more durable.

Thus we get a slight idea of the elaborate researches conducted by Dr. von Welsbach, and of the many difficulties which had to be overcome before the Welsbach mantle could become practical and commercial.

To complete the story of lights procured by the incandescence of metallic oxides, mention should be made of the lamp invented by Prof. Walther Nernst, of the University of Göttingen, early in 1899, the substance rendered incandescent being a magnesia rod through which an electric current is passed after preliminary heating. Not only is this light related to the same group as the Welsbach, not only does it give a very modern illustration of a sort of lamp mentioned earlier in the report, but (most interesting of all) in his latest work Nernst gives up the magnesia and uses the same mixtures of oxides as used in the Welsbach mantle—zirconium, thorium, cerium, erbium, etc.

A very brief description of the lamp and mantle made for use with illuminating gas by the Welsbach Light Company, of Gloucester, N. J., will give the best idea of present methods, and serve to bring out some important points with reference to the light-giving power, durability and economy of the mantle as put on the American market. The Welsbach "J" mantles (standard until very recently)

were made about as follows: A six-cord cotton thread was woven on a knitting machine forming a tube of knitted fabric of rather open mesh. This web has the grease and dirt thoroughly washed out of it, is dried, then cut into lengths double that required for a single mantle. It is then saturated in the fluid (described later), wrung out, stretched over spools and dried. Next, the double length pieces are cut into two, the tops of each piece doubled back and sewed with a platinum wire which draws the top in and provides a means of supporting the mantle when finished from the wire holder. After stretching the mantle over a form, smoothing it down and fastening the platinum wire to the wire mantle holder, the mantle is burned out by touching a Bunsen burner to the top. The cotton burns off slowly, leaving a skeleton mantle of metallic oxides, which are unconsumed, and which preserve the exact shape and detail of every cotton fiber. The soft oxides are then hardened by a Bunsen flame. During burning out and hardening, considerable shrinking takes place. This finishes the process, except the immersion of the mantle in crystalline, to prepare it for transportation, after which it is trimmed and packed. The fluid in which the cotton webbing is immersed is procured from monazite sand, which yields in the finished mantle oxides of thorium and cerium.

The candle-power of mantles of the sort mentioned is about 75 initial candle-power under gas pressure of Philadelphia illuminating gas. This means 20 candles per cubic foot per hour (an ordinary 8-foot fish tail burner gives not over 3 candle-power per cubic foot per hour). The life of the mantles is probably not much below 1,000 hours. The candle-power drops quite rapidly at first and more gradually afterwards, going as low as to one-half the initial candle-power before the mantle breaks.

It is hard to tell how much the perfection of detail in burner construction, a proper selection of chimney, and artistic features of design have contributed to procure the very large commercial use of the lamps. Without proper burners the mantle would be of small value. The details of the common burner, the peculiarities of which make it

different from the ordinary Bunsen burner in adjustment of gas and air; the gauge distributing device to spread the flame over the whole mantle and so fill the mantle are too well known to merit detailed description.

The mantle first made in America, in 1888, gave only 35–40 candle-power initial, under 10/10 pressure, using 3 to 3·2 feet of gas on 3-inch mantles, and under ordinary conditions not over 8 candle-power per cubic foot of gas used.

The new mantle, known as Balm Hill or, popularly, "Yusea" mantle, has a much more open mesh than the "J" mantle, and is made on lace-making machinery. It is thus supposed to be much stronger than the older mantle, and gives about 100 initial candle-power at the mantle when the gas and air are properly adjusted in the burner. Your committee has been unable to gather data of life or decline in candle-power in time to include them in this report.

Certain defects in the mantle light should not be entirely passed over. The mantle is exceedingly fragile and cannot be made to stand where it is subject to continued vibration; the quality of the light is such as to require the adjectives cold, ghastly, harsh, in describing it; and often a greenish tinge in the light is evident. The candle-power drops badly early in the life of a mantle, and is especially subject to this trouble where there is much dust in the air; the oxides seem to volatilize slowly from the mantles, as evidenced by the shrinking in size of strands of mantle and the white deposit on chimney, for platinum melts easily in the part of the flame where the mantles hang.

If the mantle breaks, a hole being thus produced in it, the hot flame strikes out through this, often breaking the chimney and as a secondary result destroying the mantle itself.

On the other hand, the advantages in the use of the mantle for lighting are shown not only by statements already made, but also by the fact that artificial lighting has been profoundly affected by the commercially-successful mantle. We have systems of lighting using mantles now in which the source of the heating flame is gas, gasoline, kerosene. There are systems using Welsbach mantles in

which pressure of large amount, and others in which low pressure is used. There are two great companies, the Welsbach Commercial Company and the Welsbach Street Lighting Company, that do an enormous business and deal only with the use of the Welsbach mantle in lamps using ordinary illuminating gas.

The patents held in this country by the Welsbach Light Company are very broad and fundamental, and have to do with all sorts of details of the system as well. The numbers of the patents of most importance are given below.* Over fifty in all were submitted to your committee. Some of these are not to Welsbach, and yet are for processes of importance in the manufacture of the present American-made mantle and lamp.

In consideration of the enormous advance in the art of artificial lighting made possible by the invention of the Welsbach mantle, the Franklin Institute awards the Elliott Cresson Medal to Dr. Carl Auer von Welsbach, of Vienna, Austria, for his discoveries regarding the metallic oxides which may become incandescent when heated, and for the invention of a mantle by the use of which these metallic oxides are commercially available as sources of artificial light.

*359,524,	March	15,	1887.	Carl Auer von Welsbach.
377,698,	Feb.	7,	1888.	" " " "
377,699,	"	7,	"	" " " "
377,700,	"	7,	"	" " " "
377,701,	"	7,	"	" " " "
390,057,	Sept.	25,	"	Harold J. Bell.
396,347,	Jan.	15,	1889.	Carl Auer von Welsbach.
399,174,	March	5,	"	" " " "
403,803,	May	21,	"	" " " "
403,804,	"	21,	"	" " " "
407,963,	July	30,	"	F. L. Rawson and W. Stepney Rawson.
409,528,	Aug.	20,	"	Carl Auer von Welsbach.
409,529,	"	20,	"	" " " "
409,530,	"	20,	"	" " " "
409,531,	"	20,	"	" " " "
438,125,	Oct.	7,	1890.	" " " "
463,470,	Nov.	17,	1892.	" " " "
563,524,	July	7,	1896.	" " " "

26,075 (design), Sept. 22, 1896. Geo. S. Barrows.

Also, in view of the many details wrought out by the Welsbach Light Company, of Gloucester, N. J., in putting a thoroughly practical mantle on the market, the Franklin Institute awards to them, the said company, in addition, the Edward Longstreth Medal of Merit.

Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, June 6, 1900.

JOHN BIRKINBINE, *President.*
WM. H. WAHL, *Secretary.*

Countersigned by
H. R. HEYL,
Chairman of the Committee on Science and the Arts.

CHEMICAL SECTION.

Stated Meeting, October 25, 1900.

THE USE OF BLAST FURNACE GASES IN GAS ENGINES.

BY PROF. JOSEPH W. RICHARDS,
Member of the Institute.

Practical gas engines were first put into operation by Otto, in 1870. They were for many years made only of small powers, 1 to 10 or, at most, 20 horse-power. The fuel used was illuminating gas, which has the high calorific power of 4,500 to 5,000 calories per cubic meter. About 1886, experiments showed that weaker gas could be used, and that if the gas and air mixture was strongly compressed in the cylinder before explosion, the ignition never failed. This gave rise to the running of gas engines by producer gas, particularly that made by the auxiliary use of steam, and therefore carrying considerable hydrogen. Such gas is in reality a mixture of normal producer gas with water gas; it is sometimes called Dowson gas, after the Dowson producer. It may carry 5 to 15 per cent. of hydrogen, and its calorific power vary between 1,000 and 1,500 calories per cubic meter. The use of this gas in large engines, up to 200 horse-power, gave an efficiency of 1

horse-power per 1 pound of coal per hour, and is even at present the most efficient method of generating mechanical power from coal.

The next step was a natural one; it was a consideration of the question: "Can blast furnace gases be used in gas engines?" As far as I can find, the question was first taken up practically by B. H. Thwaite, a British engineer, in 1894. Before considering his investigations, let us imagine the conditions which bear on the case.

(1) Blast furnace gases are not as rich as illuminating gas or even as producer gas, not even as rich as the poorest regular producer gas. Average analyses of rich and poor producer gas and blast furnace gases would be about as follows, in percentages by volume; on dried gas:

	Dowson Gas.	Siemens Gas.	Blast Furnace Gas.
Hydrogen	8	2	2
Hydrocarbons	2	2	2
Carbonic oxide	33	28	24
Carbonic acid	3	3	12
Nitrogen	58	65	60
Percentage of combustibles	43	32	28
Calorific power per cubic meter	1,400	1,100	950

The conclusions drawn from this comparison would be that it would be a more difficult problem to secure unfailing ignition of blast furnace gases. Indeed, the quality of these gases varies at times so greatly that they can scarcely be burnt under boilers. Any use of these gases in gas engines must therefore face this possibility of very poor gas, and provide exceptional means to secure unfailing ignition of very poor mixtures. Another incidental conclusion would have been that for a given power the engines using blast furnace gas must be larger, because of the decreased calorific power of the gases.

(2) Blast furnace gases are very dusty, from particles of the charge, and impure with metallic and saline vapors. Any prospective use in gas engines must consider this difficulty, and either provide for efficient cleaning of the gas, or provide an engine which is not affected by the dust or corroded

by the saline vapors. Cleaning of the gas would naturally recommend itself as the most likely to succeed in overcoming this obstacle.

(3) There is usually 5 to 10 per cent. of vapor of water in blast furnace gases, which would decrease the expansive force of the explosion and so decrease the power of the engine. A removal of the water vapor by condensation would appear desirable.

(4) Gas engines run ordinarily at 200 revolutions per minute, or more, while blowing engine cylinders run at 25 to 40. Gas engines, therefore, would not appear capable of supplying blast for furnaces without using gearing or other means of reducing the speed, or else by making a radical reduction in the speed of running the engines or a radical increase in the speed of the blowing cylinder. Meanwhile, until these are attained, the gas engines are suited only for higher speed machinery than blowing engines.

Such as above outlined would have been the conditions and problems confronting the investigator in this field six years ago. We will now pass on to consider how these difficulties, real and prospective, have been overcome.

B. H. Thwaite applied for a British patent on May 2, 1894 (granted May 2, 1895, No. 8670), which described methods of purifying blast furnace gas preliminary to using it in gas engines; the methods being, briefly, to take the gases from the furnace in such a manner that as little dust and metallic vapor passes into the down-comer as is possible, and as much combustible gas; then filtering the gas through wet columns of coke or brushwood, and screening it through sawdust, powdered asbestos or a fine wire screen. The claims are for using the special purifying apparatus described, in combination with thermo-dynamic motors, etc.

Mr. J. Riley* says that he was acquainted with this proposal of Thwaite in the autumn of 1894, and in February, 1895, arranged for a 15 horse-power engine to be set at work on gas thus purified, at Wishaw, Scotland. This motor ran some light machinery very successfully, and

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* *Journal Iron and Steel Inst.*, 1898, I, 33.

delivered in indicated horse-power the equivalent of 20 per cent. of the thermal value of the gases burnt. This was the first motor run on blast furnace gas. Its successful operation inspired W. H. Watkinson to read a paper on the subject before the West of Scotland Iron and Steel Institute, on March 15, 1895,* in which he discusses the power to be saved by a furnace making 100 tons of pig iron a day, as something like 6,000 horse-power, an amount quite startling, and, it must be said, much too large. The average saving will be about one-half that amount. Still, this is the first public announcement of the successful experiment and of the possibilities which it revealed.

Since 1895, numerous small motors have been in operation in Great Britain, using purified blast furnace gas. They have been mostly of 10 to 40 horse-power, but more recently up to 200, driving machinery and dynamos, but not blowing engines. In the development of large motors and their adaptation to blowing engines the Continent, and more particularly Belgium, has taken the lead.

In the beginning of 1895 experiments were also undertaken in France with small Delboutteville gas engines, but without much success, so that no records of the results attained were made public. Bailly and Kraft, however, engineers at the John Cockerill Works, at Seraing, Belgium, were sanguine of success, and installed a 4 horse-power Delboutteville motor, which began operations in December of that year, being nearly ten months after Thwaite's success in England. This motor worked steadily for eighteen months, an average of sixteen hours daily, using purified blast furnace gas. The analyses of Witz showed that the quality of the gases did not vary so much as had been anticipated, and rather approximate measurements of the efficiency showed a total of 12 per cent. After four months' running the cylinder was found to be clean, it appearing that the dust in the gases was all thrown out in the white smoke of the exhaust. No corrosive action in the cylinder was observed after two years' use.

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* *Journal Iron and Steel Inst.*, 1895, II, 471.

Encouraged by these results, drawings were prepared in 1897 for a 200 horse-power motor of the "Simplex" single-cylinder type, a four-cycle machine. This engine was put in operation in April, 1898, and a description of its installation given by Mr. A. Greiner, Director-General of the Cockerill Society, before the Iron and Steel Institute, on May 5, 1898;* while a report on its working was made by Witz to the same society August 26, 1898.† Greiner said in his announcement: "When a 200 horse-power engine has run successfully for six months, manufacturers will be emboldened to put up one of 500 or 800 horse-power to drive the blowing engines for a blast furnace or converter plant, and thence to a rolling mill engine is an easy advance."

The report of Witz, three months later, was eminently favorable. The tests had been made by Witz, together with Professor Hubert, of Liege University, engineers Bailly and Kraft, of the Cockerill Company, and Deboutteville, the gas engine builder. The gas was passed through three pairs of coke scrubbers, and then straight to the engine through a gas holder of 300 cubic meters capacity. Its calorific power varied from 800 to 1,000 calories, and averaged 981 per cubic meter. The cylinder was 0·8 meter diameter by 1·0 meter stroke, and the gas-air mixture was compressed to 7·5 atmospheres pressure before ignition. Fly-wheel, 15 tons. The detailed figures obtained were for a 24-hour run:

Average velocity	105·2 revolutions per minute.
Effective horse-power	181·2
Water used in cylinder jacket . .	72·0 kilos per horse-power hour.
Oil used for lubricating	15· grams per horse-power hour.
Grease used for lubricating . .	2·3 " " " "
Temperature of water raised . .	11·0° C.
" " discharge . . .	480° to 510° C.
Consumption of gas	3·33 m³ per horse-power hour.
Thermal efficiency	19·5 per cent.

The report remarks that "the engine works as regularly as a steam engine, and the dust in the gas is in no way injurious to its continual operation."

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* *Journal Iron and Steel Institute*, 1898, I, 21.

† *Journal Iron and Steel Institute*, 1898, II, 130.

This engine has been steadily at work now for over two years, driving a dynamo for power purposes day and night, without any wearing out of the parts, the interior of the cylinder showing only a very thin brown skin, which in no wise affects the working of the piston or the efficiency.

Calculations based on the figures obtained with this engine showed that at the Seraing furnaces, making 600 tons of pig iron daily, the gases were producing through steam boilers and engines 2,300 horse-power, with a thermal efficiency of 2·5 per cent. The same gases used in gas engines at an efficiency of 20 per cent. would be capable of developing 18,400 horse-power, leaving a surplus of 16,000 horse-power available for other purposes, which is at the rate of 2,667 horse-power surplus per 100 tons of pig iron made per day.

These surprising figures and the success already achieved stimulated experiments in Hoerde, Germany, and Differdingen, Luxembourg. At Hoerde the Deutz motor was tried, and at Differdingen a "Simplex" engine. The Cockerill Company, however, again took the initiative, and, in 1899, had constructed the largest single-cylinder gas engine ever built, connected to a blowing cylinder for furnishing blast. The engine was designed and constructed by Deboutteville, and was started on November 2, 1899. On May 9, 1900, Mr. A. Greiner described the engine to the Iron and Steel Institute,* and gave the results attained by six months' continuous working. The details are highly interesting, since this is the first gas engine to run the blowing machinery of its own furnace. They are, in abstract, as follows:

DIMENSIONS.

Diameter gas cylinder	1·3 meters (51 inches).
Stroke " "	1·4 " (55 ").
Speed	80 r. p. m. normally.

PRESSURE OF BLAST SUPPLIED.

At 84 r. p. m.	40 centimeters of mercury	(7 75 lbs. per in.).
" 94 " "	45 " " "	(8·75 " " ").
" 62 " "	62 " " "	(12·0 " " ").

Journal Iron and Steel Institute, 1900, I, 109.

POWER DEVELOPED.

561 to 725 effective horse-power in the blast cylinder.

GAS USED.

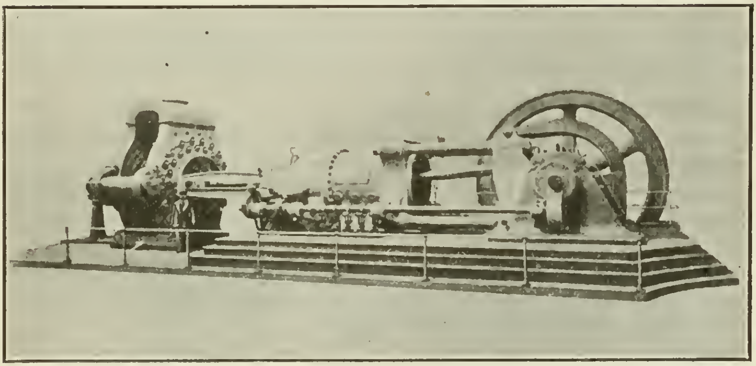
2·86 m^3 per effective horse-power hour.
2·33 m^3 " indicated " "

EFFICIENCY.

28·7 per cent. as indicated horse-power.

A consideration of the distribution of the heat energy showed approximately:

Converted into work in the cylinder	30 per cent.
Carried away by the cooling water	50 " "
" " in the escaping gases	20 " "



The Cockerill 700 horse-power gas engine and blowing cylinder at the Paris Exposition of 1900.

These tests were conducted by Professor Hubert, of Liege; Mr. Witz, of Lille; Mr. Bryan Donkin, of London; Professor Meyer, of Göttingen, and Professor Dwelshauvers, of Liege. Taking the tests, together with the fact that the engine has actually been blowing a blast furnace for nearly a year, and the question which was proposed by Thwaite has its complete and satisfactory solution. In five short years the problem has been practically solved, and an economic revolution in the working of blast furnaces is but the matter of application of the results already proved possible.

The large engine and blower shown by this company at the Paris Exposition was a duplicate of the one under dis-

cussion. It is rated at 700 horse-power on blast furnace gas, 800 on producer gas and 1,000 on illuminating gas. It was run daily for an hour, and was always surrounded by an interested group of sight-seers. Its approximate cost is given at less than $30,000, or, roughly, $40 per horse-power. This is not far from that of modern steam blowing engines, leaving out the cost of boilers and their maintenance. One may also imagine the possibility of rebuilding our horizontal blowing engines, with their steam and blast cylinders tandem, into gas engines, by replacing the steam cylinder by a gas cylinder and making the blast cylinder quicker acting.

The Cockerill Company and its concessionaries have in course of construction 35,000 horse-power of their type of engines. Other European firms have probably altogether an equal power projected. Among the actual plants now in operation are the following:

Seraing, Belgium, four 500 horse-power motors, running blowing engines.

Differdingen, Luxembourg, four 500 horse-power motors.

Hoerde, Westphalia, two 600 horse-power and two 1,000 horse-power motors, running dynamos and therewith manufacturing calcium carbide. Total, 3,200 horse-power.

Friedenshütte, in Upper Silesia, two 200 horse-power and two 300 horse-power; total, 1,000 horse-power. Used for electrical purposes.

Oberhausen, one 600 horse-power engine.

Dudelingen, two 600 horse-power and two 1,000 horse-power; total, 3,200 horse-power.

Kneutingen, two 500 horse-power for blowing.

Roechling, one 200 horse-power, two 600 horse-power.

Ruhrort, one 500 horse-power.

Barrow, England, 1,000 horse-power.

Toula, near Moscow, three 600 horse-power engines for blowing, and three 200 horse-power engines to run an electric plant; total, 2,400 horse-power.

Island of Elba, 1,000 horse-power.

In order to discuss the application of this great economy to American blast furnace practice, we must confess, to start with, that not one single example can be yet cited. Why this is so is hard to surmise; many reasons, or, rather, excuses, may be advanced; possibly our iron works have been so busy making money during the last two years that they have had no leisure to consider the question fairly and on its merits.

European practice, to start with, provides us with all the data necessary for discussing the question of applying this improvement to American blast-furnace practice. To bring out the great saving of power possible under the different conditions which may prevail in different localities and in different practices of driving furnaces, I have calculated the minimum, the average and the maximum surplus of power which may be obtained by replacing our present boiler and steam engine plants by gas engine plants. The calculations are all made on the basis of a production of 100 metric tons (98·57 long tons) of pig iron produced per day.

CASE I.—*To find the minimum surplus power.* Let us assume:

(1) A poor gas, ratio CO_2 to CO = 3 to 5 (by volume), with the composition by volume—

CO_2	15
CO	25
H	2
CH_4	1
N	57

(2) A very low fuel consumption of 700 kilos per ton of iron (1,550 pounds).

(3) A high temperature of the blast, 700° C.

(4) The requisite quantity of blast supplied at a maximum pressure of 1·33 atmospheres (nearly 20 pounds per square inch).

(5) The hot-blast stoves to have a minimum efficiency (50 per cent.) and therefore to take away a maximum proportion of the gases.

CASE II.—*To find the average surplus power.* Let us assume:

(1) An average gas, with CO_2 to CO = 1 to 2, by volume, and composition by volume—

CO_2	12
CO	24
H	2
CH_4	2
N	60

(2) An average fuel consumption of 900 kilos per ton of iron (2,000 pounds per long ton).

(3) An average temperature of blast, 550° C.

(4) The requisite blast supplied at 0·67 atmosphere (10 pounds per square inch).

(5) The hot-blast stoves to have average efficiency (65 per cent.).

CASE III.—*To find a maximum of surplus power.* Let us assume:

(1) A rich gas, with CO_2 to CO = 1 to 5, by volume, and composition by volume—

CO_2	6·0
CO	30·0
H	0·5
CH_4	0·5
N	63·0

(2) A maximum fuel consumption of 1,045 kilos per ton of pig iron (2,400 pounds per long ton).

(3) A minimum temperature of blast, 400° C.

(4) The requisite blast supplied at a minimum pressure, 0·33 atmosphere (5 pounds per square inch).

(5) The hot-blast stoves to have a maximum efficiency (80 per cent.).

We shall then obtain by the proper calculations the following results as to the surplus power obtainable by using boilers and steam engines on the one hand, or gas engines on the other:

	Case I.	Case II.	Case III.
Volume of gases per 100 k. of iron in m³	307	404	503
Calorific power of gas per m³	900	953	986
Calorific power of gas per 100 k. of iron	276,300	385,012	495,958
Assume 10 per cent. lost by leakage	27,630	38,501	49,596
Net power of remaining gas	248,670	346,511	446,362
Weight of blast, in kilos, per 100 k. of pig iron	312	388	462
Volume of blast, in m³, per 100 k. of pig iron	241	300	357
Heat units in the blast	80,210	60,900	48,362
Heat to be supplied the ovens	160,460	93,700	60,450
Net calorific power of the gas left over for boilers or gas engines	88,210	252,810	385,910
Equivalent horse-power of above gas, at an efficiency of 100 per cent., expressed per 100 tons of pig iron produced daily	5,770	16,500	25,200
Indicated horse-power developable by gas engines using this gas at an efficiency of 30 per cent.	1,730	4,950	7,560
Indicated horse-power necessary for furnishing the blast, plus 10 per cent. for hoisting, pumping, etc.	640	460	270
Surplus indicated horse-power, using gas engines, per 100 tons of pig iron produced daily	1,090	4,490	7,290

Remarks.—The surplus of 1,090 horse-power obtainable in Case I is obtainable, according to the assumptions made,

when all the conditions are the most unfavorable for the generation of power from the gases. These assumptions agree with the best modern practice in all points except the last, *i. e.*, the minimum efficiency of the stoves. It needs no argument to prove that a plant using the minimum of fuel and maximum temperature and pressure of blast would be necessarily a plant with stoves of the most approved type and efficient working. If we were to make this one change in the assumptions, and assume that instead of using stoves with an efficiency of only 50 per cent., there were used modern stoves with 75 per cent. efficiency, there would result a theoretical development of 2,780 horse-power in the gas engines, or a surplus above that required for the furnace itself of 2,140 horse-power. This, then, is the final estimate of the minimum surplus power to be obtained from a modern blast furnace running on the most economical conditions as regards the production of pig iron—reckoned per 100 tons of pig iron daily.

Case II gives a figure which applies, not to the latest type of furnace practice, but to the average type of furnace making 100 to 200 tons of iron per day—such furnaces as represented good working twenty years ago, and many of which are in operation yet east of the Alleghenies.

Case III represents a figure which is approximated by small, old-fashioned furnaces with a high fuel consumption—in other words, average practice of thirty or forty years ago. The one exception to be taken to this statement is that the stoves are assumed to have a maximum efficiency. If they have a minimum efficiency, the figure would be cut down some; but it is only a rough approximation at the best, and an actual illustration to be given will show that it is not higher than has occurred in actual practice.

To prove the correctness of these general conclusions, it will be interesting to check the figures as to horse-power by calculating the power actually raised by steam boilers and engines, and seeing if this coincides with actual results of practice. To do this we will take the surplus gas and assume it thus converted into mechanical

power, at a total efficiency of 3 per cent. (average poor practice), 6 per cent. (average good practice) and 12 per cent. (best attainable practice).

	Case I (*a*).	Case I (*b*).	Case II.	Case III.
Horse-power of gases per 100 tons of pig iron daily, at 100 per cent. efficiency	5.770	9,260	16,500	25,200
Indicated horse-power necessary for running the furnace, per 100 tons daily	640	640	460	270
(1) Indicated horse-power by steam power at 12 per cent. efficiency	690	1,110	1,980	3,000
(1) *Surplus power*, on this assumption	50	470	1,520	2,730
(2) Indicated horse-power by steam at 6 per cent. efficiency	345	555	990	1,500
(2) *Surplus power*, on this assumption	[− 295]	[− 85]	430	1,230
(3) Indicated horse-power by steam at 3 per cent. efficiency	170	280	495	750
(3) *Surplus power*, on this assumption	[− 470]	[− 360]	35	480

Case I (*a*) represents Case I of the previous calculations, *i. e.*, best modern practice with *poor* stoves. Case I (*b*) is the modification which considers best modern practice, using good efficient stoves.

The figures of assumption (1) above are highly theoretical, inasmuch as they represent the very best attainable practice with the best engines and boilers, kept up to their highest efficiency. These figures parallel those of Mr. Gordon, calculated on this assumption, contained in his paper in the *Iron Age*, of October 18, 1900. Considering the difficulties of blast furnace practice, they are an unattainable ideal. They show a moderate surplus in the case of best modern practice, and a large surplus of 1,520 horse-power in the case of average practice.

The figures of assumption (2) really represent nearly the best of modern furnace attainment. They show just about sufficient power raised to run the furnace in good practice with low fuel consumption, and a modest surplus of 430 horse-power in average practice.

The assumption (3) is nearer the average of small blast furnace steam plant efficiency, and shows a decided deficit of power for good running with low fuel consumption, and just barely sufficient power in the average running.

We will close by making some specific applications of these calculations to actual American practice, in order to check off the general reliability of the conclusions so far stated.

CASE III.—As an interesting illustration we will take the working of a small spiegeleisen furnace in Eastern Pennsylvania, which, as far as fuel consumption and general efficiency is concerned, will represent fairly well the conditions of our case, and may be taken as typical of the features of the small furnace of fifty years ago.

CONDITIONS.

Composition of gas by volume :

CO_2	3
CO	33
H	2
N	62

Spiegel produced	6,818 kilos daily.
Fuel used	29,000 " "
Flux used	19,500 " "

Carbon in spiegel	4 per cent.
" " fuel	85 " "
" " flux	11 " "
Efficiency of stoves	30 " " (iron pipe stoves).
Gas lost by leakage	10 " "
Pressure of blast	0·75 kilos per c.m². (11 pounds per inch).

RESULTS OF CALCULATIONS.

Calorific power of gas	1,052 calories per m³.
Volume of gas per day	137,204 m³.
Calorific effect " "	144,338,000 calories.
Required to heat blast, per day	50,000,000 "
Indicated horse-power of engine and pump	150

CONCLUSIONS.

Calorific effect of gases, per day		144,338,000 calories.
Lost (10 per cent.)	14,433,800	
For heating blast	50,000,000	
		64,434,000 "
Surplus for burning develops		79,900,000 "

Horse-power at 100 per cent. efficiency	5,200 horse-power.
Developable by steam at 3 per cent. efficiency	165 "
" " gas engines at 30 per cent. efficiency	1,650 "
Surplus power using steam	15 "
" " " gas engine	1,500 "

Remarks.—This little furnace barely raised enough steam power for its own needs. Using gas engines, there would have been a surplus of 1,500 horse-power, which is *at the rate of 22,000 horse-power per 100 tons of product per day.* This 1,500 horse-power would be sufficient to supply all the power needed in the works to which the furnace is attached, and save at least $50 worth of coal per day. It is to be understood that this furnace is an extreme case, and is cited simply to illustrate the general correctness of the conclusions of Case III.

CASE I (*b*).—We will present an example of very good modern practice, with exceptionally low fuel consumption (leaving the average case to the last, because of its greater relative importance).

The data are from a paper by J. Whiting, in the *Transactions of the American Institute of Mining Engineers,* June, 1891, and concern a furnace of the Illinois Steel Company, in South Chicago. The gases were exceptionally poor, the ratio CO_2 to CO by volume being 2 to 3, and the fuel consumption only 750 kilos per ton of pig iron (or 1,680 pounds per long ton).

CONDITIONS.

Composition of gas by volume:	
CO_2	15·7
CO	23·5
H	1·2
N	59·6
Pig iron produced daily	130 tons.
Fuel used per 100 kilos of pig iron	75 kilos.
Carbon in fuel, 100 kilos of pig iron	64 "
Carbon in 100 kilos of pig iron	3·75 "
Efficiency of stoves	70 per cent.
Efficiency of boilers and engines	5 "
Volume of blast per minute	247 m^3.
Pressure of blast	0·75 atmosphere.
Temperature of blast	850° C.

CALCULATIONS.

Calorific power of gas per m^3	743
Volume of gas per 100 kilos of pig iron	332·5 m^3.
Calorific power of gas per 100 kilos of pig iron	247,000 calories.
Required to heat blast, per 100 kilos of pig iron	125,854 "
Indicated horse-power of engines per 100 kilos of pig iron	220 horse-power.

CONCLUSIONS.

Calorific effect of gases per 100 kilos of pig iron		247,000	calories.
Lost (10 per cent.)	24,700		
Heating blast	97,070		
		131,770	"
Surplus for burning can develop		115,230	"
Surplus develops per 100 tons iron per day		115,230,000	"
Horse-power, at 100 per cent. efficiency		7,530	horse-power.
Horse-power by steam at 5 per cent. efficiency		375	"
Surplus power per 100 tons output daily		155	"
Developable by gas engines at 30 per cent. efficiency,		2,260	"
Surplus power per 100 tons output daily		2,040	"

Remarks.—This result is 100 horse-power less than the minimum before calculated, but a large allowance of 10 per cent. has been made here for loss, and a reduction of 1 per cent. in this item would increase the surplus power 160 horse-power. The great loss of gas occurring during charging and by leakage is an item which is being rapidly reduced by economical managers.

CASE II.—To illustrate this case, that of average blast furnace practice, we will take the data from a blast furnace plant in Eastern Pennsylvania, which is making in three furnaces 2,600 tons of pig iron a week.

CONDITIONS.

Composition of gas by volume:

CO_2	9
CO	27
H	1·8
N	62·8

Pig iron produced daily	370 tons.
Fuel used per 100 kilos of pig iron	100·0 kilos.
Carbon in fuel, 100 " " " "	82·9 "
" " flux, 100 " " " "	4·6 "
" " 100 " " " "	3·1 "
Efficiency of stoves	60 per cent.
" " boilers and engines	4·5 " "
Pressure of blast	1·3 kilos per cm² (20 pounds per square inch).
Temperature of blast	555° C.

CALCULATIONS.

Calorific power of gas per m³	873 calories.
Volume of gas per 100 kilos of pig iron	434·7 m³.

Calorific effect of gas per 100 kilos of iron . .	379,490	calories.
Required to heat blast, per 100 kilos of iron .	90,500	"
Indicated horse-power of engines for blast . .	950	horse-power.
" " " " " hoist, pumps, etc. (per 100 tons of iron daily) . .	65	"

CONCLUSIONS.

Calorific effect of gases per 100 kilos of pig iron,		379,490	
Lost (10 per cent.)	37,950		
For heating blast	90,500		
		128,450	calories.
Surplus for burning develops		251,000	"
Surplus per 100 tons of pig iron daily . . .		251,000,000	"
Horse-power, at 100 per cent. efficiency . .		16,400	horse-power.
Horse-power with steam, at 4½ per cent. efficiency		738	"
Deficit of steam power, per 100 tons iron daily		**277**	"
Horse-power with gas engines, at 30 per cent. efficiency		4,920	"
Surplus power with gas engines (per 100 tons daily)		**3,900**	"
Deficit of steam power per 370 tons daily . .		**1,025**	"
Surplus of gas engine power per 370 tons daily		**14,400**	"

Remarks.—It is an actual fact that, at the works in question, the three blast furnaces are *charged* with 800 horse-power, furnished to them by the boiler plants fired by coal. It is also a fact that nearly 10,000 horse-power is raised for the rest of the plant by coal-fired boilers, and that *all of this* could be supplied by gas engines utilizing the blast furnace gases. The saving in the coal bill alone would amount to at least $150,000 in one year. The gas engine plant to accomplish this would cost $500,000.

Conclusion.—I have chosen to conclude with this case in order to leave an adequate impression of the great industrial revolution which is imminent in the economical utilization of blast furnace gases.

METALLURGICAL DEPARTMENT, LEHIGH UNIVERSITY,
November 2, 1900.

Mechanical and Engineering Section.

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EXPANDED METAL

AND SOME OF THE USES TO WHICH IT IS PUT.

By James S. Merritt, M.E.

"Expanded metal" is an excellent illustration of an article which has been found to be applicable to far greater extent and for purposes not thought of in the beginning by the inventor, than to those which he had in mind when he first conceived the idea. When Mr. John F. Golding, of Chicago, first attempted to make expanded metal he expected to use it as a material for fences, window guards, etc., and he called it "slashed metallic screening." It is probable that less than 1 per cent. of the output of expanded metal at the present day is used for these purposes, the greater part of it being used now in the fireproof construction of buildings. This development is largely due, however, to Mr. Golding's efforts, and there are at the present time four companies in the United States and five or six in Europe manufacturing expanded metal. There are also a number of local companies engaged in the fireproofing of buildings, and $10,000,000 is probably a conservative estimate of the capital now invested in the expanded metal business in its various forms.

The Franklin Institute was the first scientific society to recognize the merits of expanded metal by awarding, in the year 1892, the John Scott Medal to Mr. Golding for his invention of expanded metal, and this action has since been justified in a remarkable degree. It would be difficult to find any other name for the material which would so well describe it, and the French "metal deployé" and the German "Streckmetall" both follow the American idiom.

Expanded metal is cut from a sheet of open-hearth steel, expanded, or opened into a netting of any desired size of

mesh or section of strand. The operations of shearing the steel and opening the meshes are simultaneous, and are performed cold. No material is wasted, as there are no pieces cut out. The finished sheets are from three to eight times as large as the original sheets of steel, according to the size of the meshes and the width of the strands.

The grades of expanded metal which are in commercial use to-day vary from $\frac{3}{8}$-inch mesh, cut from No. 27 B. W. G. steel, to a diamond mesh 5 x 12 inches, cut from No. 4 gauge steel. The sheets are usually 8 feet in length, and the machines which do the cutting have to be slightly more than this in the clear between the housings. They are very heavily and substantially built, as it is necessary that they run with smoothness and accuracy, for the shear blades have to be adjusted with great care to make a clean cut. I show you on the screen the front of one of the machines in the works of the Central Expanded Metal Company, near Pittsburgh. The shaft of this machine is 8 inches in diameter, although it is reinforced at two points in 9 feet by bearings upon the lower side of the heavy lintel which extends across from housing to housing. This will give an idea of the substantial construction which is necessary in order that these machines may do good work. The plate of steel to be cut is placed upon the table on which the workman is resting his left hand, and is then fed in by degrees under a clamping device which holds the sheet down solidly against the bed while the cutting is being done. The original method of cutting expanded metal did not involve any stretching of fibers of the steel. The sheet was fed through the machine in a diagonal direction. The first stroke of the shear blades cut one mesh and pushed it down at right angles to the plane of the sheet of steel. The second stroke of the blades produced, in a similar manner, the next three meshes, while the third stroke produced five meshes. The distance between the housings of the machine limited not only the length of the sheet, but also the breadth, and most of the old machines were unable to produce a sheet more than 8 feet in length by 4 feet in breadth. The sheets of expanded metal were never quite

square, and the thickness of the steel which could be worked in this way was limited. Before placing the sheets of steel in the machine it was necessary to cut them to the exact size to give the desired sheets of expanded metal.

In 1894 Mr. Golding invented and patented another method of cutting expanded metal, and this has proved far superior to his former invention, and of wider range. The sheets of steel are now fed through the machine in the direction of its shorter axis instead of diagonally, as in the old method. The shear blades, instead of being each set diagonally and in a different plane, now consist of a stationary straight lower blade and a series of diamond-shaped blades in one vertical plane carried by the movable upper head of the machine. The distance between the points of adjacent blades determines the length of the greater axis of the meshes, while the shape of the blades and the stroke of the machine determine the width of the meshes. In changing the machine from one mesh to another, it is not necessary to change the lower blade, but merely to change the upper blades.

We will suppose that it is desired to cut 3 x 6 inches mesh expanded metal from a sheet of No. 10 steel. Expanded metal above No. 14 gauge is usually cut with an approximately square strand, or in other words, the width of the strand is about equal to the gauge of the steel. The sheet of steel is placed in the machine with its edge projecting at the back $\frac{1}{8}$ inch beyond the lower shear blade. The machine is started, and the movable head which carries the set of diamond-shaped shear blades comes down upon the sheet. The points of the row of upper blades, some sixteen in number, strike the top of the sheet of steel, and begin to shear it away from the rest of the plate, and at the same time to push downward in a vertical direction the strand so formed. The steel must be of the proper quality, as the elongation amounts to over 10 per cent., the corresponding reduction being greater in the thickness than in the width of the strand in about the ratio of 1·16 to 1·00. The upper knives are stopped in their downward movement just before they have travelled far enough to

completely sever the strand from the original sheet. The strand is left connected with the sheet by a strip of solid steel, which is technically known as "the bridge." The head is then raised and the plate is shifted laterally a distance equal to one-half the long axis of the mesh which is being cut. It is then fed the width of one strand beyond the edge of the lower plate, and the machine is ready for a second stroke. When the head descends, the points of the upper blades strike upon the bridge, and begin the shearing process at that point. The manner in which the sheet of expanded metal grows in size is shown in the illustration.

After a sufficient number of strokes to form a sheet of expanded metal of the desired width, the feed of the sheet of steel in a horizontal direction is intermitted during one stroke of the head. The upper blades cut through the "bridge" on the same line as the shearing done during the preceding stroke, and as a result the expanded metal is entirely separated from the solid sheet of stock.

When expanded metal is made by this improved process the sheets are exactly square, and the width of the sheet is only limited by the width of the original sheet of steel, or by the possibility of removing the sheets of expanded metal, which issue vertically downward from the back of the machine. It has been customary to build a pit behind the machine to get the necessary room, and it is not possible, at the present time, to turn out sheets of more than about 8 feet in width by 9 feet in length, the latter dimension being limited by the distance between the housings of the machine. It is evident that it would be possible, should occasion demand, to cut a 48-inch wide sheet of No. 10 steel into a single sheet of 3-inch mesh expanded metal about 32 feet in width.

Steel is the material generally employed, but it is equally possible to expand brass, aluminum, or other metals, and considerable of this has been done to meet special requirements. The sheets of steel have to be annealed, pickled and treated in various ways during the process of conversion into expanded metal, but these processes are not inter-

esting in character, and we shall, therefore, not go into them in detail.

It has been argued that the process of cutting must cause incipient cracks in the steel, which would greatly reduce its tensile strength, and an elaborate series of tests was made in 1897 at the Massachusetts Institute of Technology which showed conclusively that such is not the case. The test pieces were considerably reduced in area at the point of rupture, and the appearance of the fracture was normal. The uniformly satisfactory condition of the steel in expanded metal is, in great part, due to care in the selection and preparation of the stock, and the fact that the shear blades are kept in much better condition and more accurately adjusted than is usually the case with shearing machines.

It has been already stated that expanded metal is described commercially by giving the width or short axis of the diamond mesh and the Birmingham gauge of the original sheet of steel.

To describe the material exactly there should also be stated:

(1) The angle formed by the long axis of the meshes and the strands of the expanded metal (usually about $12\frac{1}{2}°$), which is determined by the shape of the upper shear blades; and,

(2) The width of the strands (measured at right angles to the original thickness of the plate), which depends upon the "feed" of the machine, which can be varied within certain limits. The feed is usually about one-tenth greater than the thickness of the plate.

The weight of expanded metal proportioned as above can be found from the equation:

$$W = 100 \frac{t^2}{m} \tag{1}$$

in which W is pounds per square foot.

t thickness in inches corresponding to the gauge number.

m length in inches of the meshes.

The constant 100 depends upon the angle of the meshes and the width of the strands.

We will now consider some of the practical applications of expanded metal, which may be divided into the following groups:

(1) Fireproofing of buildings.
(2) Concrete structures.
(3) Exterior of buildings.
(4) Miscellaneous.

(1) *Fireproofing of Buildings.*—The principal use of expanded metal at the present day is for the fireproof construction of buildings and as a "binder" in concrete structures of all kinds. The extent of this use is shown by the fact that over 9,000,000 square feet, or 200 acres, of various grades of expanded metal were used in the buildings of the Paris Exposition. This is greater than the area bounded by the Delaware and Schuylkill Rivers, Market and Sansom Streets.

In the United States there is scarcely a prominent building that has been completed during the last ten years in which there is not more or less expanded metal. It was first used in building construction as a substitute for wood lath; it was secured by staples to each side of wood studs, and was found to give a much better support for plaster than had ever been obtained by the use of wood lath. This form of construction will resist the action of fire for a considerable time, but the next step was to do away with the wood studs by the substitution of some form of light steel bars, or rods.

By properly forming these supporting members any desired architectural effects can be had and at comparatively slight expense. The groined and panelled ceilings in the Library of Congress, Washington; Carnegie Library, Pittsburgh; Free Library, Boston; City Hall, Philadelphia; and the new Masonic Temple, Boston, are a few examples of this form of expanded metal construction.

In this system there is nothing to shrink or warp, so that there can be no cracking of the finished surface, and the

perfect "key" of the plaster on the expanded metal lath is a guarantee that the plaster will never fall off and that the most elaborate decorations may be applied with entire confidence.

About eight years ago it occurred to Mr. Golding that a partition could be built in which but one surface of lath would be used instead of two, as had been the custom, and the result was a "solid partition" $1\frac{1}{2}$ or 2 inches thick. The writer is free to confess that he did not believe these partitions would do more than support their own weight, until he had actually seen them in place. Light steel studs, usually of $\frac{3}{4}$ x $\frac{3}{8}$-inch channel section, are set up at distances of about 16 inches, and expanded metal lath is then secured by wire ties on one side of the studs. The lath is plastered from the front, and when the mortar has "set" another coat of plaster is placed upon the rough "keys" which form the back of the first coat. One or two more coats of plaster are added to each side of the partition, which can be given any desired finish. These partitions are not intended to carry any load, but are merely for the purpose of dividing rooms. They are proof against sound to a remarkable degree, and the most reasonable explanation of this property which has yet been offered is that the sound vibrations, entering one side of these partitions, are intercepted by the network of steel and carried off laterally to other parts of the structure and so dissipated, instead of being allowed to pass directly through the partition. They also resist fire wonderfully well, as shown at the Home Life Insurance Company Building, New York City, and the Merion Cricket Club fires a few years ago.

About the year 1892 Mr. Golding made the experiment of embedding expanded metal in a concrete plate for flooring, and this invention has rapidly found its way into favor, the floors of some of the largest buildings in the United States having been constructed upon this system. It is really a modification of the Monier system, which was introduced in Europe in 1878, and by the use of which remarkable results have been attained in France and Germany. The principle involved is to place a sufficient amount of steel

wherever the structure is likely to be subject to tensile stresses, and to depend upon the concrete in compression only. The combination of steel and concrete in this way is an ideal one, as very light steel members can be used in most cases, and these are held firmly in place and protected by the concrete from corrosion, the steel in turn reinforcing the concrete against rupture under tension.

By reason of its peculiar construction a sheet of expanded metal laid upon a flat surface will touch the latter at a few points only, and as a result of this property it is not necessary to offset a sheet of expanded metal before applying the concrete. On account of the ease with which the sheets can be handled, and its greater power of "binding" the concrete, expanded metal is considered far superior to the straight Monier rods, which have to be laced together at the site.

In the construction of expanded metal floors, cinder concrete is generally used for two reasons; first, on account of its lightness; and second, on account of its excellent fire-resisting qualities. Cinder concrete has withstood, undamaged, many severe fires, both in practice and in test. The reason of this is apparent when we consider that Portland cement is burned at a temperature of over 4,000° Fahrenheit, while the temperature of the furnaces from which anthracite boiler cinders are obtained is even higher.

The roof of the new Mint Building in this city will be of expanded metal and cinder concrete, for the various departments of the United States Government have been prompt to appreciate the advantages of this system. It is possible to drive nails into the cinder concrete, so that slate or tiles can be secured directly to the concrete without the use of wood, which is always liable to decay.

(2) *Concrete Structures.*—Expanded metal has come into favor with civil engineers as a "binder" for concrete foundations, walls, etc., and has been largely used by the Engineer Corps of the Army in fortifications and gun mounts.

It has also been used, embedded in concrete plates carried by steel beams, to form the decks of bridges, and in concrete arch bridges. The principle involved in all these con-

structions is the same as in the case of floors in buildings, *i. e.*, to supply steel, in sufficient amount and the proper places, to resist all tensile stresses. A bridge 134 x 60 feet, which has just been built by the Erie Railroad over its tracks through East Newark, N. J., is an excellent example of the first type, while a number of county highway bridges have been built near Pittsburgh which illustrate both types. In the construction of a bridge at Sea Girt a considerable amount of money was saved recently by the substitution of vertical concrete plates, with embedded expanded metal, in place of masonry wing walls and abutments.

Expanded metal has been used to a considerable extent in the construction of concrete sewers. Several years ago, in the case of a sewer in the Neponset Valley, near Boston, it was impossible without going above the grade line to secure sufficient filling on top of the sewer to prevent its bursting upward under the pressure of water from within. The Metropolitan Sewage Commission finally adopted a construction in which a sheet of expanded metal embedded in concrete was used to tie down the upper part of the sewer, which was of oval shape. This plan was entirely successful, and the engineer of the Boston sewers later on overcame a similar difficulty by the same method.

Expanded metal has been used in the new sewer system of Worcester, Mass., and an illustration of it appears in the report of the engineer, which has just been published. In this city the Bell Telephone Company used expanded metal last winter in a sewer adjoining their large manhole at the Northeast corner of Seventeenth and Filbert Streets. It was desired to have the side of the sewer as thin as possible so that it would not occupy valuable space, but the west wall of the manhole rested directly upon the top of the sewer, and was liable to great loads from the street above.

(3) *Exteriors of Buildings.*—From the use of expanded metal lath for interior partitions, etc., it was natural to pass to exterior construction. A large house was built in Pittsburgh in 1892, the outer walls of which consisted of a wood frame covered with expanded metal lath, plastered with

Portland cement mortar. This proved such an unqualified success that many buildings all over the United States have since been built on the same principle. Old dilapidated brick or frame buildings can be veneered and made to look like new structures.

A recent instance of such a transformation is the Pennsylvania Railroad Station at New Brunswick, N. J., which was partly frame and partly brick which had been painted so many times that it would have been impossible to secure the adhesion of plaster. This station now presents a most attractive appearance. It is pebble-dashed all over so that neither brick nor weatherboards are visible, and no one would recognize the dilapidated structure of a year ago.

The surface of such buildings can be finished in many different ways. They can be trowelled smooth in Portland cement and sand, or can be pebble-dashed. A more elaborate treatment will yield the effect of quarry-faced or ashler masonry, which can be given any tint to harmonize with the surroundings.

In the construction of new buildings in which a greater degree of "fire resistance" is required, or which, to use the popular term, are to be "fireproof," the expanded metal in the exterior walls is carried on steel studs. The large buildings of the Walker Bros. Soap Works, at Pittsburgh, have been subjected to raging fires both from within and without at different times, without injury. The construction can be either of the "solid" type or double, with an air space, where it is important that very little heat pass through the walls.

(4) *Miscellaneous Uses.*—In addition to thousands of miles of fencing, a list of the many curious ways in which expanded metal is employed would include riffles for placer gold mining, bird cages, door mats, clothes lockers in manufacturing establishments, tree guards and brake shoes.

The "Diamond S" brake shoe is made of cast iron, but before the molten metal is poured a bundle of expanded metal lath, cut to approximately the size of the brake shoe, is placed in the cavity in the sand, which is then filled in the usual manner. The makers of this shoe claim for it not only

increased ability to hold the wheel, but also much greater life for the brake shoe without greater wear of the wheel.

In conclusion, there seems to be no limit to the uses to which this material can be put, and it is another example of that ingenuity which bids fair to gain for the United States the commercial supremacy of the world.

THE SIGNIFICANCE OF CRYSTALLINE FORM.*

By W. F. C. MORSELL.

Matter.—The endeavors to define matter at the present day are too many to count; but as they are confessed failures, the outcome is a forcible reminder that the real nature of matter is insoluble. We must be content to know that matter exists with tangible properties and uses. The existence of matter in the state of a subtle, undivided substance, extending throughout finite space and serving as a medium for the modes of motion manifested in energy, is axiomatic, self-evident and conclusive to scientific minds. This extended substance is the ether, supposed to be a continuous, ungranulated state of matter, out of which the various chemical elements have been developed by the action of force.

In contact with gross matter the sense of touch gives us a perception of mass as composed of particles, granulated with fine or coarse grains. Such matter becomes less appreciable to the senses as the particles or grains are more and more separated in space; but the various stages of separation are marked by recognizable properties and are known as states of matter, such as solid, liquid, vapor and gaseous.

Theory of Gross Matter.—A theory of gross matter in solid form is approachable by assuming a generalized, geometrical figure, such as the sphere, to represent a unit of mass. According to such a hypothesis, an elementary

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chemical substance should be conceived as a group of spheres of uniform size and of a mass specific to that element. The liquid state can be represented in rolling contact and unstable equilibrium; the solid state, by spheres also in contact but in stable equilibrium.

Having selected a suitable material (steel), let a sphere of unit volume stand for a particle of hydrogen; then the other elements may be represented by steel spheres whose cubic contents correspond with the atomic weights or volumes. This hypothesis of spherical units supplies stereo-chemistry with sets of units which can be arranged according to chemical formulas in such crystalline envelopes as belong to the formulas in nature. The units in such an envelope should be arranged in the order of their melting points, the highest melting point giving the core of the figure. This method of investigating form and structure by the close packing of spheres may be extended to vegetable and animal morphology and histology, since protoplasm differentiates into cells with spherical envelopes and these cells are assembled and arranged, during the process of growth, into configurations depending on the resolution and composition of the forces at work. This program reduces all the phenomena of nature to the sway of the laws of motion.

Inertia.—A normal experience of the sense of touch shows gross matter to be destitute of self-moving force and with a tendency to seek stable equilibrium in a zero of motion, which is known as rest, or repose. This is the primary sense of the adjective "inert"—destitute of power to move itself. It is a property of matter, depending on mass, that it resists change of position when at rest; and when in motion it resists change of direction and also requires a countervailing force to bring it again to rest. All calculations of energy consider rest as the zero of motion. Combining these notions, we arrive at the property of matter called "inertia," the persistence of mass in any state imposed upon it by force. Matter, apart from force, thus remains in repose until the conquest of inertia by force.

Force the Cause of Energy.—"Energy," in its modern use, has been confounded with "Force." Energy is best described as a mode of motion, *e. g.*, heat, light and electricity are modes of motion differing only in wave length. It is self-evident that such modes of motion in a substance destitute of self-moving force can be set up only by the entrance of a cause sufficient to overcome the inertia of the mass with which the cause is dealing. To dispense with such an initial conquest of inertia involves the necessity of stripping matter of its most distinctive property; however, if we revive Sir Isaac Newton's definition of force, "that which produces motion or tends to produce it," we can then make a rational statement as to the origin of modes of motion. *Force is the cause of energy.* This force, by definition, has no inertia, and, being devoid of the most distinctive property of matter as well as having the ability to overcome inertia, must be regarded as *immaterial.*

Specific Stability.—Matter passing from a liquid to a solid state seeks a position of stable equilibrium, and, if the solidification takes place on a horizontal plane, a second plane is formed by accommodation as part of the surface of the new form. In proportion to the area of this new plane there will be a stability with its center in a line normal to the plane surface. When a chemical element solidifies under conditions favorable to crystallization it acquires an envelope of plane surfaces, and, if left free to seek a position of rest, it will show a center of stability in a line perpendicular to its largest plane face. This is a specific stability peculiar to every substance to which nature has assigned a specific geometrical envelope. The idea of a specific envelope in geometry is known to be a relation between a mass and its bounding surface; the cube has a surface larger relatively to the enclosed mass than any other figure; the sphere has the smallest surface relative to its contents. As in a series of geometrical figures the number of plane faces increases, the faces diminish in area and the total envelope decreases in superficial area until the least surface is reached in the sphere. In such a series the stability varies inversely as the number of the faces, and directly as the area of the largest face.

To make the matter plainer, let us consider three crystals: a cube, an octahedron and a quartzoid, or twin hexagonal pyramid. The square face of the cube evidently has a larger area than the triangular face of the octahedron, and the isosceles triangle of the hexagonal pyramid is again less than the equilateral area of the octahedron's face. If these figures rest on a horizontal plane a greater amount of force is required to tilt the cube than to tilt the octahedron, and, again, the octahedron resists overturn more vigorously than the quartzoid. This specific stability is modified by the specific density of substances and the resistance to overturn will equal the product of the area of the largest crystalline face and the specific gravity of the material.

Form and Internal Structure.—Crystals grow by the deposition of planes. These planes of growth become planes of cleavage, *i. e.*, of least cohesion to such an extent that some crystals separate into laminæ of thicknesses bearing appreciable relations to wave-lengths of light. So minute are the thicknesses that laminæ of mica may be used to differentiate shades and tints of color in polarized light.

To illustrate the effect of the laminæ, recall the laminated wood used in making models of ships. Alternate layers, dark and light, are glued together, and when cut finely, present the ship-curves intersecting the planes of dark and light material. Suppose a loosely made model with the layers slightly separated instead of closely glued. Let the separation be sufficient to allow the water to move between the planes with the wash of the waves. Such a ship model, if it met a system of waves, must present planes of least resistance to which any transmitted waves would be accommodated by the compounding momentum of the water meeting the resistance of the planes of the model; the transmitted waves will then issue, following the lines and planes of least resistance imparted to them in their passage, and these vibrations reduced to one plane constitute plane polarized light.

When any system of waves, heat, light or electricity enter a crystal, the vibrations are accommodated to the planes of least cohesion. The effect of lines of least and

greatest resistance at a right angle to each other is to divide a transmitted system of waves into two beams with their vibrations at a right angle to each other, and that beam which met the greater resistance shows the retardation by its deviation from the original path of the ray, this division of the ray being characteristic of double-refracting crystals in which the axes are unequal. The figure of such crystals is elongated in one direction and shortened in another at a right angle, and the faces of such a crystal are usually diamond-shaped.

A flexible square (see *Figs. 15* and *16*, Plate I), corded with string so as to divide it into smaller squares, when deformed by stress into a diamond, separates the strings in one direction and crowds them together in a plane at a right angle with the direction of their separation. Such a model represents one of the laminæ of a doubly-refracting crystal, and the pairs of acute and obtuse angles at the corners denote a strained condition of the interior arrangement of the particles in that face; now, as the whole crystal is built up of recurring laminæ, the structure of which is similar, therefore the internal arrangement of particles must correspond in parallel planes to the structure indicated by the external faces, and, in diagonal planes, the structure must be the resultant of the intersecting planes; so that the form of the crystal is a true projection, in three dimensions, of the internal structure.

Form and Stable Equilibrium.—The conditions of stable equilibrium for spheres in contact with planes composing the envelope of a cube may be studied experimentally in cubic shells made of thin sheets of cork and mica. The first three figures (*Figs. 1, 2, 3*) in Plate I show the three arrangements which can be made inside of a cube with steel spheres. *Fig. 1* shows the closest packing; it contains fourteen balls with the balls in contact on the diagonals of the face. This diagonal line represents the edge of a regular tetrahedron as a rational edge measured by the whole number, three. The middle ball is the apex of an octahedron composed of six balls. On the face of a large cube the square arrangement of the balls in contact would

show the squares set diamond-wise. The squares with edge lines parallel with the cubic edges show the balls not in contact. This position of the squares with open or closed edges is vital in relation to the number of spheres which can be contained within a cube of given size.

Fig. 2 shows the arrangement of the spheres in squares with rational edges parallel to the cubic faces—the arrangement in all three planes being alike. The structure of such a cube shows the largest possible interspaces, and the arrangement of the structure is homogeneous in every direction normal to the faces, but the balls are in maximum unstable equilibrium.

Fig. 3 gives a packing in which the rows of balls in alternate layers rest in the hollows of the adjacent rows. The packing is in stable equilibrium with the smallest possible interspaces, but it will be seen that the face has dissimilar corners and the solid angles at two opposite diagonal corners are truncated. The dimensions resulting from such packing are isometric normal to the faces and asymmetric along the diagonals joining pairs of solid angles measured through the cube.

In *Figs. 4* and *5*, Plate I, adjoining faces of the same figure have been shown. *Fig. 4* shows the closed square of balls with edges parallel to the cubic faces. The next layer shows nine balls, one in the hollow between every four of the face layer. This is stable equilibrium, but in *Fig. 5* the adjoining face shows a difference of arrangement and a loss of the cubic dimension between the vertical faces of the cube. This shows a closest packed arrangement which could never be isometric.

In *Figs. 6, 7, 8, 9* the series of shapes alter in a way to be appreciated only by considering the packing of spheres in relation to a sequence of figure ranging from minimum density and maximum volume to minimum volume and maximum density.

Form in Relation to Density.—An assemblage of small spheres may be used for a concrete geometrical investigation of the relative position of mass units referred to an envelope of plane surfaces such as constitutes a crystalline

figure. A set of bicycle balls of one size may serve the purpose, as these are exact spheres.

On a level surface, a piece of felt, arrange four balls in contact bounded by a square. The interspaces are the largest possible for contact, and the balls are in unstable equilibrium; but if the boundary be changed to a diamond, the new position gives the smallest possible interspaces and the balls are in stable equilibrium. One pair are in contact on the short diagonal, and on the long diagonal another pair are far apart; the lines of separation were at a right angle in the square, but are now oblique, and these are lines of greater and less resistance. One arrangement is more dense than the other.

If a solid figure be built up of a set of spheres of uniform size, the planes parallel to rectangular faces in a cubic figure hold balls in unstable equilibrium, and the interspaces will be the largest possible for spheres in contact; this is minimum density and maximum volume. Without walls this group will fall apart, but a practical model may be secured either by threading wooden balls on an elastic string, or, better, by making a hollow cube of cork and mica, with an edge measuring, say, three diameters on the interior, the shell thus obtained holding twenty-seven balls. See *Figs. 6*, *7*, *8* and *9*, Plate I.

Now, let us suppose a series of figures, hollow shells of the same inside edge, to hold additional sets of balls of the same size and number as the cube. Let the second figure have two diamond faces, the third four, and the fourth six diamond faces, the obtuse angles of all the faces being 120°. These hollow shells are now to be filled with the balls and then, on examination, it will be evident that the interspaces diminish in size and the density increases as the faces successively pass from squares to diamonds, until the last figure with six rhombic faces has maximum density and also a minimum volume, the surface having decreased in every succeeding figure.

An example of the law of inverse squares may be found by comparing the line functions of the solid angles of the last figure of the series with the similar functions of initial change in the second figure.

The final figure with none but rhombic faces, which exhibits maximum density from one point of view, is hexagonal when assigned a place among the classes of crystals; but this figure may be analyzed into isometric elements, an octahedron and two tetrahedra. It is probably more than a coincidence that the greatest specific gravities are to be found in crystals of isometric and hexagonal figures.

Form as the Result of the Composition and Resolution of Forces.—In nature, where the transitions of growth pass from the curves of soft, plastic material to the straight line boundaries of polygonal figures assembled in tissues, if the pressures are symmetrical the resultant lines are symmetrical. *Fig. 10* shows the collapse of a copper tube under pressure, forming a series of superposed equilateral triangles, and *Fig. 11* is the same tube shown in a cross-section with the hexagonal plan resulting from the superposition of the equilateral triangles. A number of closely packed spheres would collapse into geometrical solids with plane faces. In *Figs. 12, 13, 14* are shown the results of packing spheres in cylinders. Glass tubes are used. In *Fig. 12* the balls form a wave line the amplitude of which depends on the diameter of the tube and the length of the undulation on the size of the spheres. In *Fig. 13* the composition of two such wave lines is shown to be a double spiral. In *Fig. 14* the composition of several spirals is shown, forming a hollow tube like the stem of a vortex; the vortex may be experimentally shown by small spheres in a glass funnel. Two such funnels arranged end to end in dumb-bell fashion would represent the axis of a sphere in which the surface particles flow in at one end and out at the other end. In microscopic cell-life the amœba form floating in a liquid takes such a spherical shape with a flow along the axis in at one pole and out at the other; virtually this corresponds to the smoke ring conception of an atom, with a very small opening along the axis, in which the flow would be a vortex motion. Such an axis would give positive and negative poles to a spheroidal atom.

Form and Chemical Composition.—The numbers called "atomic" are now also recognized as "mass numbers" in chemical teaching.

Let it be assumed that the chemical elements have been derived from one substance, and that any element may be represented by a set of spheres, all of the same cubic con-

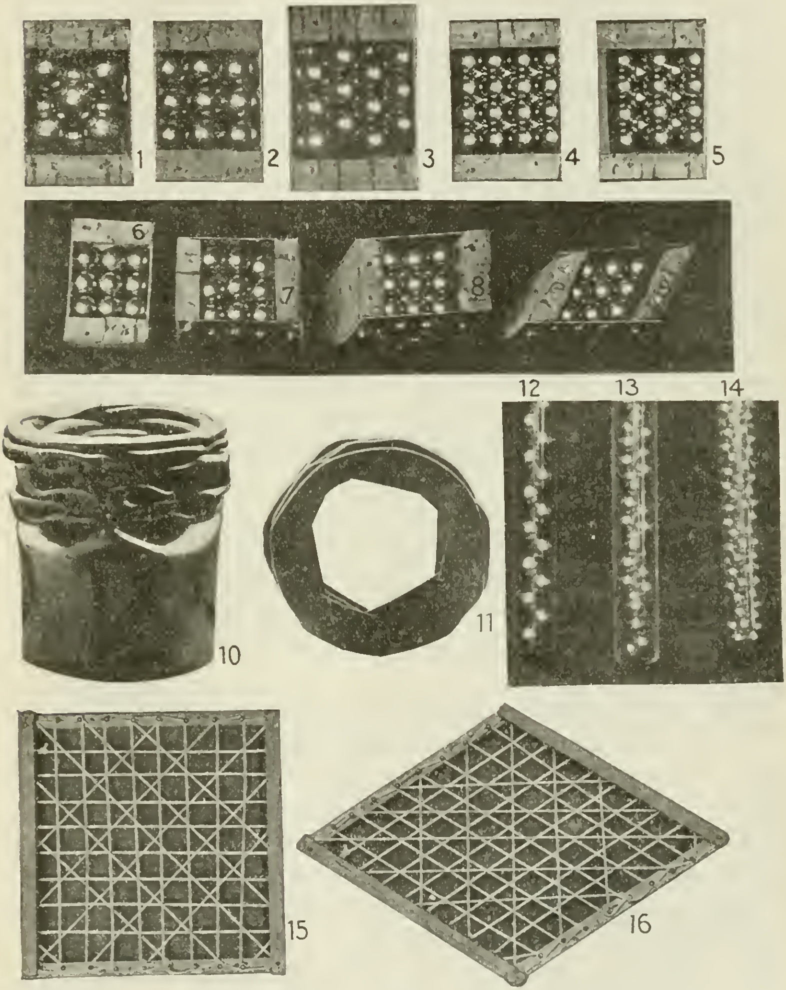

PLATE I.—The close packing of spheres, illustrating form and structure resulting from the composition of forces.

tents as the mass numbers assigned to that element as its atomic weight; then a stereo-chemical investigation is possible by using a hollow crystal model such as nature has

assigned to a known chemical formula. Two or more sets of balls, differing as the atomic weights, may be selected by the aid of the proper formula and fitted experimentally into the crystal envelope. The problem must first be attacked as regards stable equilibrium according to the light afforded by the concrete geometrical series of figures beginning with the cube, previously described in this article.

The order of the melting points will show the relative positions of the elements, the highest forming the core of the figure. It may be necessary to use a multiple of the atomic weight to solve the problem.

The elements usually assume isometric forms which it is known can be built out of spheres of uniform size. Those instances in which elements are not isometric crystals can be met by supposing the spheres to have an elasticity specific to any one particular substance. These forms differ by being larger or smaller submultiples of the volume of the cube as though cohesion is only able to hold together a specific number of mass units of a specified atomic weight. Every isometric crystal is a submultiple of the cube, by bevelments and truncations, which take place at submultiple segments of the edge lines of the cubic envelope. Nature thus gives geometrical multiples as well as multiples by weight. *The universe appears to be a vast concrete multiplication table.*

It is not possible to build the more distorted figures of crystals with spheres of one size, but they can be built with ellipsoids; so physicists have made a pet of this figure; and yet it suffices if the spheres be elastic; for in packing, such spheres may become ellipsoids: but the building of the distorted shapes may be effected by using spheres of different size, and it is this fact which gives a hope of a rational method in stereo-chemistry. Whenever a new element enters a crystal, the angles are slightly altered, and this is exactly what occurs when a different size of spheres is combined with the uniform set in an isometric figure.

Calcium Fluoride.—Although the isometric figures are mainly elemental, there are exceptions. Calcium fluoride, although a compound, forms a cube.

The formula calls for 2 parts by weight of fluorine and 1 part of calcium. The atomic weight of calcium is 40, and that of fluorine is 19.

The core of a cube is a tetrahedron, and may be considered as formed by the composition of four lines of attraction, acting normally to the four faces of the tetrahedron. Four units of calcium, impelled by such forces, would resolve into a position of stable equilibrium, representing a regular tetrahedron in its well-known position in a cube. The four corners of the cube remain to be filled with fluorine, which would be in a gaseous state at a temperature which would allow the calcium to become solid. Let the amount of fluorine ($19 \times 2 = 38$) for one unit of calcium be represented by thirty-eight small spheres, one of which is equal to the hydrogen unit. This quantity is just sufficient to fill out the corner of the cube.

Form and Attraction.—Instead of holding the spheres together by the external compulsion of an envelope of tangent planes, a beautiful demonstration of figure as the result of the stable equilibrium of a set of uniform spheres may be had by using a magnetic field, which can be formed by placing a flat sheet of some thin substance over the poles of a strong horseshoe magnet. On the plane surface thus obtained three bicycle balls will arrange themselves in stable equilibrium in one plane, and if a fourth ball be placed near and over the first three it will seek repose in the depression between the balls below it.

Now reverse the magnet, and if the group of balls does not overtax the power of the magnet, the tetrahedron will preserve its figure as the result of the composition of forces in the magnetic field. Any group of spheres in a magnetic field resolving its forces symmetrically in three dimensions must assemble in a geometrical figure by the laws of attraction.

If two or three sets of bicycle balls be used to an extent of weight within the sustaining power of the magnet, figures with truncated corners and bevelled edges can be formed similar to the faces on natural crystals.

Figs. 1 and *2* in Plate II are the illustrations of a possible

formation of calcium fluoride in a cubic crystal. *Fig. 1* shows the effect of attraction in holding four particles of calcium on the poles of a horseshoe magnet. The transparent cube shows the position of the four particles in a cube forming the regular tetrahedron as the core of the cube and leaving the four corners vacant. *Fig. 2* represents the amount of fluorine as a gas required to fill the vacant corner. The masses of lime and fluorine are calculated according to the atomic volumes, *i. e.*, the atomic weight divided by the density.

Fig. 3 shows a goniometer set at the measure of the acute angle of a face of Iceland spar (calcium carbonate) and in this angle it is experimentally demonstrated that the spheres representing calcium and carbon, calculated with a volume corresponding to the atomic weights as mass numbers, when arranged in stable equilibrium under attraction on the face of the poles of a magnet, exactly fill the angle of the crystal in the plane of the face.

Form and Cleavage.—When the Abbé Haüy accidentally dropped a tray of crystals the breakage revealed that the small fragments were forms resembling the larger masses to which they belonged before their separation. From that time it has been a recognized truth that a crystal has cleavage planes of least cohesion by means of which it may be broken into smaller figures which are repetitions of the larger form.

This figure is a definite shape specific for every substance, whether elementary or complex, depending on chemical affinity. Now it takes but one step in generalization to carry us to the unavoidable conclusion that this theory of cleavage provides for the existence of a plane geometrical figure, a crystal of infinitesimal size, as the simplest conception of a unit of mass or a molar unit, the existence of which may be assumed as unquestionable even though it be invisible to the eye.

To carry the analysis still further, a geometrical investigation can be made as to the relation of spheres packed in stable equilibrium and also as to the relation of sets of spheres to an envelope of plane faces such as form a geome-

trical shape. This investigation is capable of showing not only the relation of one set of spheres of uniform size to such an envelope of tangent planes, but can be used also to examine the more complex cases where two or three sets of

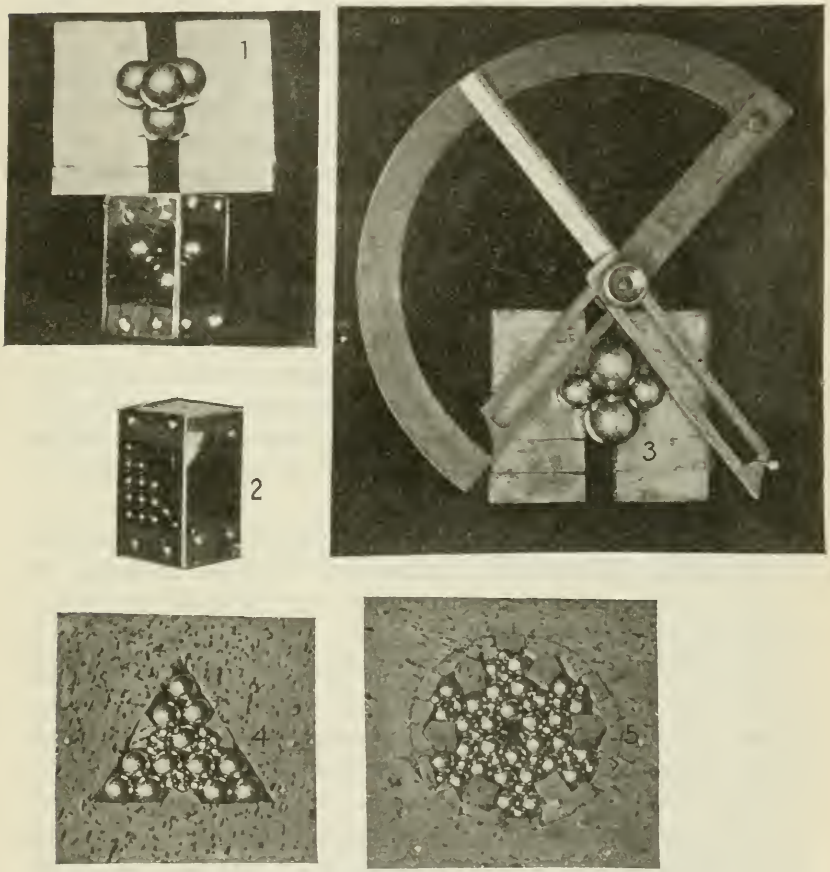

PLATE II.—Stereo-chemical models, with the spheres in multiple volumes representing atomic weights.

spheres of different size may be packed together as in the case of a chemical compound.

This relation of crystalline figure to cleavage and to a generalized spherical unit supplies education with a new set of models for teaching stereo-chemistry.

To resume what has been just said, the true chemical molar or molecular group, giving an envelope to the atoms, is an infinitesimal crystal as suggested by cleavage and the atoms may be conceived as small spheres assembled in stable equilibrium inside of a resulting geometrical figure the shape of which is the necessary result of the number and also of the relative size of the spheres.

Form and the Unity of Nature.—It is well known that nearly all the chemical elements crystallize in the isometric or cubic form. These forms differ from the cube by bevelments on the edge and truncations at the corners which occur at submultiple points on the cubic edge. The figure thus outlined is always an exact submultiple of the volume of a cube, but of what cube is not known. The truth of such submultiple geometric volumes corresponds to the well-known relation of multiples by weight. This concrete multiplication table in both volume and weight could not exist unless the crystalline forms contained a common substance, and the presence of a common substance shows the derivation of the chemical elements from some unit mother-substance underlying the universe.

As chemical compounds have a volume which is the sum of the elemental volumes, the resultant crystal must also be a submultiple or multiple of the same cube to which the isometric forms are related.

This view confirms the present kinetic theory of matter and seems to afford a valid proof of the unity of nature towards which the whole scientific world seems to tend under the guidance of recent discovery.

Form and Planes of Symmetry.—If a solid figure be cut through an edge line and along the diagonal of a face, so as to divide the solid into two parts of equal size, the parts will show two new faces made by the cut; both these fresh surfaces are the same in figure; they are called planes of symmetry. The two halves must weigh the same and may be alike in shape, but the shapes may also be unlike. If the half figures correspond both in shape and weight then the new dividing plane surfaces are figures representing a plane of symmetry both of figure and of volume in the original

solid. If the half figures be dissimilar in figure but alike in weight the dividing plane is said to be only a plane of symmetry of volume and not of symmetry of figure. Some crystals have no planes of symmetry of figure, but all crystals have planes of symmetry of volume.

Make a diagram of such a plane and examine the deviations from 90° by dropping perpendiculars on convenient lines, either vertical co-ordinate, a side or a bissectrix of an angle. Examine the lines to see if any intersecting points divide the lines into submultiple segments.

In the plane of symmetry of the regular tetrahedron the deviation from 90° is 19° 28′ 44″, and the sine is ·3333333 or $\frac{1}{3}$, which is the tangent of the angle 18° 26′ 4″, which belongs to the field of symmetry of another class of figures known in crystallography as orthorhombic. Angles which are not submultiples of the circle, but whose lines are submultiples of the radius, belong to the planes of symmetry of volume of geometrical solids, especially of crystalline shapes, but these submultiple segments of the radius may also belong to angles which are submultiples of the circle.

We may call this system of angles sequence angles because they connect classes of solid geometrical figures.

Sequence of Figure.—In space of three dimensions there are three degrees of freedom. Suppose nine balls in contact, surrounded by a square boundary, making one plane in a cube. To complete the cube, two more similar squares are needed; then these squares may be so placed, one above another, as to show the freedom in every plane and by successively shifting the squares two degrees may be destroyed, one degree by a shift to the right, another degree by a shift at a right angle to the first, the balls being in stable equilibrium in those planes where the balls of an upper square rest in the hollows between the rows of balls in the lower square. The third degree of freedom can only be destroyed by at last changing the square boundaries so that the hollows and crests of the rows coincide. The shift in all these changes is measured by a half diameter and irresistibly reminds one of the theory of half-wave interference in light. Stable equilibrium is reached by a series of

internal half-wave shifts which reduce the interspaces between the balls to the least possible size. Notice that, as the interspaces diminish, the series of figures pass from transparency to opaqueness. Here we have a sequence of figure related to density, stable equilibrium and permeability.

The cube, as the symbol of three-dimensioned space, has all of its faces normal to one another, and may be regarded as a graphic representation of free equilibrium in a fluid or liquid state from which crystals are formed.

Moreover, the axes of the cube are not only rectangular, but they are equal, so that they serve admirably to represent not only a primary class of crystals, but also their homogeneous structure; since if any figure has unequal axes, or the axes are inclined, in the plane of the extended axis or oblique axis there is a corresponding disturbance of the particles by strain or displacement. It is possible to analyze the cube into a series of figures with rational axes corresponding to the six types of crystals.

The axes of the sequence of crystalline figure are as follows:

Isometric	1	8 : 8 : 8
Tetragonal	2	2 : 2 : 8
Hexagonal	3	$\sqrt{\cdot 5} : \sqrt{\cdot 75}$
Orthorhombic	4	8 : 4 : 2
Monoclinic	5	8 : 5 : 2
Triclinic	6	8 : 5 : 3

In this scheme the monoclinic and triclinic are derived from the orthorhombic by a transposition of parts. These type figures are all exact submultiple volumes of the cube and conform to the law of multiple volumes by weight. In nature there is a sequence by which one class of figures may pass into another class of more heterogeneous structure. This sequence is accomplished by the dimorphisin of carbon, sulphur, selenium, carbonate of lime and the feldspar group. For example, the orthorhombic passes into monoclinic and the monoclinic into the triclinic class.

Form and Graphics.—By graphic design the composition and resolution of forces are represented by a diagram in

which both the direction of the forces and their relative magnitude correspond to the length and direction of the lines. These lines are limited to the plane of the diagram, but the outlines of a crystal, being in three-dimensioned space, have a greatly increased power of delineating complex action. It is known that in all crystal figures edge lines are harder than the faces; again, the apex of a solid angle is harder than an edge line. A concrete composition of forces takes place in these lines and points, and a skeleton model of any crystal is a configuration of its forces, a diagram of configuration in three-dimensioned space. The short lines between obtuse angles are measures of least resistance, and the longer lines between acute angles are measures of greatest resistance. A crystalline figure is nature's edition of the graphics of physical force.

Potential Energy.—Potential energy is the energy of a particle due to its position. This is taken advantage of in modern machine-tools in constructing cutting edges. The figure of a crystal in a state of revolution suggests similarity to a cutter. If the planes of a cube, meeting in a trihedral solid angle, are successively presented to an emery wheel with a narrow face, the wheel is dressed while it cuts, and the intersection of the resultant curves makes a drill-point unrivalled for boring, without splitting, a cross-section of wood. The particles in a crystalline figure have potential energy by natural assignment to the face, the edge line or the apex of a solid angle. All statements of the hardness of minerals are made in terms of the potential energy of a diamond point.

Form and Environment.—The nearest approach to crystallization without environment is the formation of a snow crystal in the upper atmosphere. Such crystals exhibit a freedom of development when not interfered with by limiting conditions, by accomplishing the lawful end of their organizing force, perfect symmetry. Every snow crystal is an approximately complete geometrical design of exquisite beauty.

When the same material crystallizes in contact with the windows and sidewalks, some examples retain the angles of

the hexagonal system in the inclination of the rays to a central stem; again, all straight lines vanish and fern-like curves take their place, so that the frost crystal presents a vegetative pattern.

> "The glory of the celestial is one, and the glory of the terrestrial is another."

The failure of symmetry is evidently due to environment. It appears to be an example of molecular coalescence without the agency of colloids. This molecular coalescence, that accommodation of crystalline material by which the crystal surrenders its normal figure to enter into the shells and bones of animals, has been induced by microscopists, the mere location of a salt in a colloid solution being sufficient to show the conformity of the crystallization to its environment. The susceptibility of the crystal to its environment continues through all the stages of its growth. There is a continuous action and reaction between the crystal and its surroundings, usually registered in zones.

The formation of a crystal is a dynamic development governed by mathematical law, realizing perfect symmetry in proportion to the non-interference of "natural selection," which is a negative influence and can never be recognized again as the chief factor in evolution. A program of "dynamic" development reaching to the limits of the physical universe underlies all environment and is winning a progressive triumph for the survival of the best.

It is strange that this system of dynamic development, dependent on the laws of motion and the composition of forces, has been missed by the acute investigators who have advocated the well-nigh exclusive influence of environment. They have done nobly with their partial truth, but the neglect of the data supplied by crystallization has deprived them of the fundamental law of nature, which strives after the realization of perfect symmetry and suffers its loss temporarily to serve, not hopelessly, but with patience and humility, under the yoke of accommodation to environment; "the ethics of the dust" manifestly seeking after perfection at the cost of sacrifice, which wise men, in all ages, know to be the true law of progress. It is well to close with a

definition of dynamic development, namely: The mode of the manifestation of force is a development in which form and structure are the results of the composition and resolution of the forces of growth, tending to produce perfect symmetry, and progress towards this symmetry is the measure of the subordination of environment to the laws of motion.

ADDENDA.

Form and Stable Equilibrium.—Much attention is being paid by English students to the problems of stable equilibrium represented by assembling spheres in the closest possible packing. It may or may not be the case that atoms are in contact, but the atoms are supposed to occupy an average position in relation to one another capable of representation by an assemblage of spheres at the centers of which the atoms may be situated and even in a kinetic equilibrium the phenomena may be experimentally investigated by the relations existing among a group of spheres with a geometrical envelope of plane faces enclosing them.

In a cubic envelope the balls may be packed in three different ways, which can be best understood by inspecting the models as represented in the illustrations which have been prepared from photographs.

In the *Fig. 4*, Plate I, the empty cubic space was packed with four balls in a row in the closest square order possible and the second plane of balls was packed in the hollows of the lower first row with the result that the adjoining faces present show a different distribution of the balls in planes at a right angle with the face that was first laid in position. This arrangement could not result in a cube, for in a cube the face with a four-square of balls does not allow the balls to be in contact, but gives an open square.

A good illustration of dilatancy by heating may be had by regarding the heat as acting first on the outer layer, which in the act of expansion could no longer have its balls fit exactly in the same hollows which they fitted exactly before the heating.

Note that if a difference of dimension occurs in such

packing the difference of one line from another is necessarily a half-diameter for the displacement that allows one row of balls to occupy the hollows of the next row beneath. This suggests a reason for the rational or multiple relation in the axes. Dimension measures must show a difference like the displacement of crystals.

Note.—Figs. 15 and *16*, Plate I. The model of an elastic square is used to illustrate the structure of a single lamina in a crystal. The lines parallel to the side are unelastic cords which undergo no alteration in length when the square is deformed under stress, the only alteration being in the shape of the area included between the lines. The effect of the stress is a strain in the direction of the long diameter of the resulting rhombus and the lines in this diagonal are made of elastic material. When the model is changed under stress there are two unequal elasticities present represented by the short and long diagonals at a right angle with each other.

Note.—Figs. 4 and *5*, Plate II. In the two models of the structure of a snow-crystal, the triangle represents the hexagonal element as the accepted formula suggests in which a molecule of water contains one oxygen atom with two atoms of hydrogen, the steel ball standing for oxygen weighing sixteen of the unit balls, one of which represents hydrogen. The hexagonal model has two balls for the oxygen, each ball weighing eight of the hydrogen balls. In this case the balls are exact geometrical multiples, as the smaller has a diameter just one-half the diameter of the larger, the sphere following the cubic ratio in which a cube of half the edge of another has one-eighth of its contents. The sphere which equals twice eight involves the celebrated problem of the duplication of the cube.

Mining and Metallurgical Section.

Stated Meeting, held Wednesday, October 10, 1900.

THE CHEMISTRY AND PHYSICS OF CAST IRON.

Being a continuation of the discussion of MR. KREUZPOINTNER'S paper entitled "RIDDLES WROUGHT IN IRON AND STEEL." See *Journal of the Franklin Institute*, May, 1900.

MR. KREUZPOINTNER:—The extended discussion of my paper, "Riddles Wrought in Iron and Steel," shows a very gratifying interest by the engineer in applied metallurgy. If the discussion has drifted to that coy and intricate subject—cast iron—I am not surprised, since cast iron is a metal presenting many riddles for solution by the investigator.

It must be a satisfaction to our foundrymen to see so much interest manifested in cast iron, of which it was predicted that it would soon give way to steel. However, from all appearances the iron founder will live to a good old age, and the increasing liveliness of discussions and investigations of the properties and qualities of his product should encourage the foundryman to renewed energy in the observation and study of the peculiarities of cast iron.

It is by no means an unalloyed joy to discuss so complicated an alloy as cast iron, and not being a practical foundryman, my remarks can only be fragmentary and tentative.

In the examination of the qualities of cast iron we do not have the advantage, as we have it in steel, of being able to trace the causes of good or bad qualities back to their origin along the line of results of work from the ingot, along the heating, hammering or rolling. Cast iron remains in its primary condition as it comes from the mould, and the founder's skill and judgment are the principal factors in determining the value of his product.

Hence the duty devolves upon the foundryman to join hands with the scientist in order to increase our knowledge and advance his interests.

For the purpose of investigating the nature of cast iron our knowledge of steel helps us but little.

Structural steel is so far removed from its primary condition of the cast ingot, and even in its primary condition differs in its nature from cast iron so considerably, that a comparison is quite out of question.

Cast iron is a heterogeneous mixture of a number of chemical elements without any modification of the conditions in which they exist, by mechanical treatment, as in steel.

In cast iron we are not justified in making one factor responsible for certain qualities.

For instance, if an iron is weak, it is not necessarily weak because of an excess of graphite.

To make the graphite alone responsible would be like jumping at conclusions. To say that too much combined carbon makes cast iron useless would be a denial of the every-day fact that cast iron with high percentages of car-

bon, a minimum of which may be combined or graphitic, will be of exceeding usefulness to the engineer for specified purposes with all degrees of combinations between maximum and minimum percentages.

The excellent and timely work of the American Foundrymen's Committee on Standardizing the Testing of Cast Iron, with such eminent foundrymen as West and Moldenke as guiding minds, has advanced far enough to show us in what direction we might proceed in the future in a systematic inquiry of those peculiarities in cast iron which are still riddles to us, waiting to be solved in our technical colleges and by the members of this section.

The form or forms which the chemical elements in cast iron seem to assume during the last stages of solidification of the iron seem to have more influence on its final quality than the total percentage of this or that element.

Jueptner von Johrnsdorf hints on the appearance of carbon in five or six different forms in iron, and chemists tell us that other elements may, and do, assume two different forms. Hence, as long as we do not know with at least approximate definiteness under what conditions these various forms of the carbon and other elements are produced and found in the every-day product of the foundry, and what relation these various forms assume to each other, and what influence they exert on the physical qualities of the resulting casting, it would seem as if it would require the earnest co-operation of the practical founder and scientist to find a way out of these difficulties.

Our knowledge of cast iron will remain fragmentary until the scientist can tell the foundryman with what mixture, molten and poured at such and such a temperature, the various elements are in their most favorable relation to one another, producing best results. And even if we should ever attain to such a desirable degree of knowledge, much of the success in a foundry will ever depend on the individual skill and good judgment of the founder.

It is probably due to the successive modification of the elements and consequent reaction upon each other which gives us a good casting when, by analogy, if we con-

sider each element present only in one form, we should expect a bad or inferior casting.

Let us look for a moment at a few of the results of the Foundrymen's Committee on Tests.

CAST A.—Ingot Mould Iron, soft Bessemer mixture. The total carbon is 3·87 per cent.; graphite, 3·44 per cent.; leaving only ·43 per cent. combined carbon. The 1-inch square test bar, green sand, had an average transverse strength of 2,015 pounds, with a deflection of ·127 inch. The 4-inch square test bar, green sand, gave a transverse strength of 90,000 pounds, with a deflection of ·091 inch.

CAST B.—Dynamo Frame Iron. Total carbon, 3·82 per cent.; graphite, 3·23 per cent., leaving ·59 per cent. combined carbon. The 1-inch square test bar, green sand, gave a transverse strength of 2,360 pounds, with ·120 inch deflection. The 4-inch square test bar, green sand, gave a transverse strength of over 100,000 pounds, with a deflection of ·055 inch at 100,000 pounds.

In both these cases we have an excess of graphitic carbon, and since graphite itself is of low strength, we might conclude, from a purely theoretical standpoint, that such iron is worthless. Yet it is considered good enough for dynamo frames.

If we go to the other extreme we have:

CAST D.—Chilled Roll Iron. Total carbon, 2·36 per cent., of which only ·06 is graphitic.

The 1-inch square test bar, green sand, gave a transverse strength of 2,810 pounds, with a deflection of ·270 inch, while the 4-inch square bar, green sand, gave a transverse strength of 174,460 pounds, with ·140 inch deflection.

CAST E.—Sand Roll Iron. Total carbon, 3·04 per cent., with no graphite. The 1-inch square test bar, green sand, gave a transverse strength of 3,070 pounds, with a deflection of ·218 inch. The 4-inch square bar, green sand, gave a transverse strength of 168,640 pounds, with a deflection of ·140 inch.

Here again, according to theory, we might expect such excessive hardness and brittleness as to make the iron practically useless. In all four cases the deflection shows

the important influence of size of casting on the final quality of the metal. May we not surmise that, in these very carefully planned and equally carefully executed casts, the carbon and all the other elements were distributed through the mass of the iron uniformly in such variously modified forms as to support, rather than weaken, one another, and thus, together, helped to produce satisfactory results? If we could extend our search in that direction we might be able to find a satisfactory explanation for at least some of the perplexities which vex the foundryman's life.

There is another important factor determining the quality of cast iron which deserves our closest attention and the consideration of the foundryman. This is the phenomenon of segregation, of a dissociation of the chemical elements from one another when the fluid iron leaves the cupola or furnace, running through all stages of cooling of the metal.

In steel the effects of this tendency of the elements to segregate are more or less modified by the subsequent heating and rolling of the ingot.

In castings these modifying influences and agencies do not come into play, and the effects of segregation remain in full force. Other things being equal, segregation is the result of an excess in the iron of one or another, or several, of the chemical elements, and of the temperature of melting and the rate of cooling.

Segregation will begin with the first cooling after the fluid metal has reached the highest degree of melting heat and will continue, for all we know, through all degrees of cooling to the last stage of solidification of the casting. If the three necessary conditions of segregation are combined under favorable circumstances, the result may be the formation of the characteristic pine-needle crystals of iron, but more generally its results are a difference in structure in different parts of a casting, if the casting was large enough, with a consequent difference of quality in different parts and internal strains.

As far back as 1830, Rudberg in Germany, and, in 1834,

Fournet in France, found that a fluid solution of two metals may separate into two distinct bodies, each with a different melting point. It has been observed that with certain metallic solutions the variations in the melting and cooling points of the different constituents may result in a true chemical combination of a portion of the fluid until the saturation point is reached in that particular portion.

The rest of the constituents, being in excess of the necessary quantity to form a true chemical combination, will form a mechanical mixture. These two bodies, or portions, will then solidify into one mass, but each with a different melting point, rate of cooling and physical qualities.

According to Roberts-Austen and Jueptner von Johrnsdorf, the true chemical combination and point of saturation in iron is reached with 95·7 per cent. iron and 4·3 per cent. of carbon, with a melting point of 1,130° Celsius, while the melting point of pure iron is given by Osmond as 1,530° Celsius.

According to high authority,* a minimum of temperature controls the melting and solidification of a given proportion of a mixture of elements. If a liquid mixture containing a given proportion of elements is cooled at the minimum temperature, or freezing point, agreeable to each element, then all the parts of a mixture will solidify uniformly at that temperature and no segregation would take place.

If, however, the mixture is composed of proportions of elements not solidifying uniformly at a minimum temperature, then the surplus or excess of these elements will solidify at a temperature higher than the given minimum.

If, then, we have a mixture of varying proportions of elements which do not all solidify at one temperature, we may expect as a result a series of formations of groups of elements as we go down in the scale of temperatures from the highest degree of melting point to the point of complete solidification, and the last of these groups will determine the practical value of the product.

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*See Lehman, "Molecular Physics," p. 740.

Thus we can readily perceive the almost endless complexity of conditions arising in a cooling mass of cast iron, especially if the mass be large and hot, with ample time for play among the elements to produce partial or complete absorption, saturation, equalization, segregation, exchange and interchange among the various elements, according to their affinity, the law of crystallization, degree of heat of melting and rate of cooling, until the last group of elements, the mother metal, or so-called eutectic, is formed and the mass is completely solidified in every part.

These considerations seem to lead to the conclusion that it is somewhat hazardous to attempt to squeeze the practical work of mixing, melting, casting and testing of cast iron into the straight-jacket of cast iron rules and formulas until we know more of the causes and conditions which produce these complex phenomena. Meanwhile, and probably for a good while to come, we will have to trust to the practical skill, experience and sound judgment of our colleague, the foundryman.

MR. A. E. OUTERBRIDGE:—Responding to the call of the President of the Section, I would say that I have little to add to my remarks made during the first discussion of Mr. Kreuzpointner's paper. It may be well, however, to revert, for a moment, to the queries propounded by Professor Howe and my replies thereto by way of further explanation.

Professor Howe has approached the subject of cast iron from the standpoint of an expert in steel; my experience, on the other hand, during the past twenty years, has been confined almost entirely to cast iron. Hence the wide divergence of our views regarding the value of carbon as a constituent of cast iron. Applying his knowledge that "steel reaches its greatest tenacity with about 1 per cent. of carbon" to the complex combination of iron, carbon, silicon, manganese, phosphorus and sulphur (not to mention traces of other elements) commonly classed as cast iron, the Professor propounds an interesting and novel proposition, viz.: "If we apply this to cast iron, then the metallic part reaches its greatest strength with 1 per cent. (of carbon), *i. e.*, all combined carbon in the cast iron as a whole in excess of 1

per cent. is a source of weakness. It is also a source of brittleness and hardness. All graphite causes weakness and probably brittleness. * * * In short, all carbon in excess of 1 per cent., whether combined or graphitic, weakens the metal."

In my reply I have taken an opposite view because I do not consider that steel and cast iron are comparable with each other, at least with respect to the part that carbon (whether combined or graphitic) plays in imparting strength or weakness to the metal. In the case of steel all of the carbon is combined with the iron, while in cast iron carbon may be all graphitic, as in the softest grades, all combined, as in "chilled" or white iron, or part graphitic and part combined, as in strong gray cast iron.

The physical properties of steel and cast iron are as distinct as though the two metals were composed of entirely different elements, like gold and silver; and while it may be true that there is no sharp line of demarcation between cast iron and steel, the two metals, as commonly known and used, are radically different both in the solid and in the fluid state. For example, we cannot forge or weld cast iron; so, also, we cannot produce two entirely different qualities in different parts of one steel casting, by varying the rate of cooling from the fluid state, as in the case of a chilled cast-iron car wheel, where the "tread" is white iron, hard as steel, and the "plate" is gray, soft and comparatively ductile.

It should be understood in my former statement, viz., "I believe that the strongest and most ductile cast iron is that which contains a maximum of carbon (about one-half combined and one-half graphitic) and a minimum of all other elements except iron," that I did not mean to imply that it is practicable to obtain such metal as this from any blast furnace. I was merely discussing an ideal condition.

In point of fact, cast iron containing a maximum of carbon has usually a very small amount of that element in the combined form; the metal is, of course, soft and ductile, and has, therefore, comparatively little strength.

There are some reasons for believing that when cast iron is in the molten state nearly all of the carbon is in combi-

nation with the iron, but, on solidifying, the carbon separates either partly or wholly into the graphitic form; the more slowly the metal cools, the more complete is this separation. Practical advantage may be taken of this knowledge to make castings of large dimensions having much greater strength and ductility than could otherwise be obtained. If a large casting having thick section be poured from iron which shows good tensile and transverse strength in a test bar of, say, ½ inch, 1 inch, or even 1½-inch section, the metal in the casting will be of very different quality from the test bars. The grain will be "open" and the metal will be weak.

If, however, the composition of the charge in the cupola be such that the small test bars are white or mottled and, of course, brittle (because nearly all of the carbon is captured in the combined form, owing to the quick cooling), the metal in the large casting will be strong, comparatively fine grained and perfectly gray, due to the separation of carbon during the prolonged process of cooling.

The skill of the metallurgist, with the co-operation of an intelligent foundry foreman, can in this way secure, day by day with reasonable certainty, the production of castings having the qualities of strength, ductility, rigidity, hardness, or softness, as may be required, not only without increasing the cost of the materials, but, in many instances, with considerable economy. The most expensive grades and brands of pig iron are not necessarily the best for all kinds of work.

I regard the temperature of pouring cast iron as a very important feature in obtaining good, strong castings. You may pour from one ladle two castings of the same size and form, one at the proper temperature, the other may be too hot or too dull. In either event you will have two castings of different qualities, although the chemical composition of the metal may be the same.

Apropos of this, I will briefly mention an interesting investigation made in 1879 by Dr. Dudley, chemist of the Pennsylvania Railroad Company, the facts relating to which I found recently in reviewing my note books for the year 1881.

Ten old car wheels were selected for investigation, five

of which had failed after running an average of 24,349 miles each; the other five wheels had an average record of 122,463 miles in service. Drillings were taken from the five good wheels and also from the five poor wheels and analyzed with the following results:

AVERAGE CHEMICAL COMPOSITION.

	Carbon.	Phosphorus.	Silicon.	Manganese.	Sulphur.
5 good wheels . .	3·242	0·403	0·776	0·391	0·083
5 poor wheels .	3·306	0·396	0·714	0·449	0·090

The difference in chemical composition is scarcely more than might be looked for in analyses made from drillings taken from different parts of one wheel, and seem to indicate that the great difference in wearing quality was due to causes other than variations in chemical composition of the metal in the good and bad wheels. The relative proportion of combined and graphitic carbon is not given in these reports, but I believe that in the gray iron plate of a car wheel nearly one-third of the carbon is in combination with the iron and two-thirds in the graphitic form.

There appears to be a "critical temperature" for pouring cast iron in order to secure the best results, and it is, therefore, desirable that some portable, inexpensive, and fairly accurate instrument should be devised for reading, at a glance, the temperature of molten iron. Some years ago, an optical pyrometer, made in France, was brought out for this purpose, but so far as I am informed it has not proved entirely satisfactory, and I should be glad to know whether any members present have had practical experience in the use of pyrometers for determining the temperature of molten metals in their daily work.

In conclusion, I may say that I consider Mr. Webster's "Note on a Proposed Scheme for the Study of the Physics of Cast Iron," published in 1895, so comprehensive that I am unable to add any important suggestions thereto.

MR. ASA W. WHITNEY:—As the breaking loads and deflections of the bars quoted by Mr. Kreuzpointner do not give a very good idea of the effects of composition and of rates of cooling (due to ratio of perimeter to area of cross-section $\frac{P}{A}$), I have reduced the figures to the more com-

parable ones of modulus of rupture and average modulus of elasticity.

Cast.	Bar.	Modulus of Rupture.		Modulus of Elasticity.	P / A
			For Exact Dimensions.		
A	1″ square.	36,270	—	6,870,000	4
	4″ "	25,312	—	1,655,000	1
B	1″ "	42,475	—	8,510,000	4
	4″ "	28,126	—	3,030,000	1
D	1′ "	50,580	44,125	4,510,000	4
	4″ "	49,065	49,065	2,070,000	1
E	1″ "	55,250	51,567	6,050,000	4
	4″ "	47,430	43,515	2,000,000	1

In *Trans. of Am. Inst. of Mining Engineers*, March, 1895, there is a report of some of my experience with the pyrometer referred to by Mr. Outerbridge. Continued use tires the eye, which must be treated as part of the instrument and protected from glare of iron and occasionally standardized.

I would protest against the considerable amount of expense and study wasted on average analyses in cases such as that quoted by Mr. Outerbridge.

Note the date when chemical work was not so freely applied to cast iron as now. It is not likely that Dr. Dudley would now, after twenty-one years' further experience, use average analyses in such an investigation, except possibly where it was known that the five wheels averaged were cast under similar conditions and from the same cupola tap of one heat. If the wheels or any other scrap or pig iron is to be broken and mixed for use as melting stock, an average analysis is, of course, entirely proper. But as an argument for the importance of the pouring temperature or the insufficiency of the complete analysis of castings such comparisons are as defective as the belief that a fixed proportion of the total carbon is graphitic in the plate of good standard car wheels. That depends upon the *sort* of good composition employed.

As indicating roughly how the significance of the chemistry of these various good and bad wheels is, as usual, almost obliterated by the averaging of each lot, a rough formula, which can be improved, gives, when applied to the averaged analyses quoted, figures in the ratio of 100 to 96 for the good and poor lots respectively. If applied to the identical composition of each wheel, greater variations, like the following, would probably appear. The analyses tested below by formula occur in a paper by an inspector of the C., B. & Q. R. R.,* and indicate that my formula is worth improving and that analyses are too individual to be averaged until reduced to other terms.

	Relative Figure.
Wheels that failed in thermal test	78·95 to 82·50
" " stood " "	83·34 " 89·18
" " failed under fifty blows Barr drop . .	82·75 " 90·79
" " stood " " " " . .	96·50 " 100·

Another formula compares chilling capacity fairly well. Chill was evidently deficient in some of the above wheels.

PROF. H. M. HOWE:†—Steel and cast iron form two continuous and coterminous divisions of the iron-carbon series, the influence of carbon of course being modified by that of other variables. Now, I am confident that Mr. Outerbridge will see, on reflection, that it is not particularly reasonable to assume, as he seems to, that inferences about the constitution of one of these two divisions, drawn from our large store of knowledge of the constitution of the other, must necessarily be fallacious, and, therefore, to brush them aside without critical examination. The greater part of our reasoning in this world has to be by analogy, and the proper treatment, I had always supposed, of such reasoning was not to brush it aside as necessarily leading to false conclusions, but to examine its processes and test its products by comparison with known facts. That it needs the check of comparison with facts, as the case of manganese steel shows, by no means renders reasoning by analogy useless. It is, indeed, in my opinion, in large part because those interested in cast iron have failed to avail themselves of this mode of

* Mr. G. W. Beebe, *Iron Trade Review*, October 25, 1900.

† Communicated.

illuminating their subject that their knowledge is in its present unsatisfactory state, and he would be a narrow professor of metallurgy who, if an expert in so closely allied a subject as steel, should have no mature views on the constitution of cast iron. It appears to me that Mr. Outerbridge has offered neither evidence to rebut my conclusions, nor valid objection to my reasoning.

I have elaborated my views on this subject in a paper which will shortly appear in the *Transactions of the American Institute of Mining Engineers.*

In my original remarks I gave a reaction by which I suppose that sulphur is removed from cast iron in the blast furnace, by the reduction of lime, which, until so reduced, exists as lime silicate in the slag. For simplicity in stating the reaction I wrote to the CaO of the lime as if it were free, supposing that every reader would understand that this was my reason. To my surprise, a friend asks me if I think that the lime is free in the hearth of the blast furnace. Certainly not; it is the lime of the lime-silicate in the cinder that has to do with desulphurizing.

ELECTRICAL SECTION.

Stated Meeting, held February, 1900.

A FEW REMARKS ON X-RAYS AND OTHER RAYS.

By Arthur W. Goodspeed.

[ABSTRACT.]

I ought to ask your indulgence for the apparent lack of relation between the several topics which it seems to me not inappropriate to bring to your attention this evening. The avowed object of my friends in getting me here was to "help out," but judging from what I have heard and from what I see is to follow, you hardly need any assistance, so I will be as brief as possible.

In the first place, I would like to speak of a probable improvement in the inductorium as an X-ray generator, suggested by my own experience and subsequent measure-

ments. This matter was referred to more at length in an article by myself, "On the Technic of X-Ray Work," in the *Philadelphia Medical Journal*, January 6, 1900. A quotation from the article makes clear my point:

"Difficulty is often met in adjusting the interrupter for different rates on account of the sparking which results. In this case the capacity of the condenser is probably not suited to the set of conditions that must be met. In other words, the time of a complete cycle of operations, and the ratio in which this period is divided between closed and opened circuit in the primary, is of considerable importance, and is clearly related to the self-induction of the coil and the capacity of the condenser intended to take up this extra current. If the capacity be too small the condenser will be only partially effective, and sparking will result at the break.

"Adjustments should be made so that the actual interruption of the primary current shall be as sudden as possible. This results in a rapid variation in the magnetic flux through the iron core, which induces in the secondary a rapidly increasing electromotive force. This act of breaking the primary, however, produces a self-induction in the coil, which in itself tends to retard the suddenness of the break by causing an arc across between the points as they recede from each other. It seems as if the current possesses a sort of momentum, on account of which it becomes most difficult to stop the flow instantly. If, however, a condenser of large capacity be connected around the break, the extra current will flow into that. The condenser evidently must be of capacity sufficient effectively to absorb all the charge that would otherwise tend to jump between the contact points. But a very important part of the phenomenon is yet to follow. The best iron core will not alone lose its magnetism except after a time which is considerable when compared with intervals of the minute order of magnitude we are contemplating. To effect this necessary result the condenser at once discharges back through the circuit, the effect being to demagnetize the core very rapidly, thereby inducing an enormous electromotive force in the secondary.

"I am told by the makers that on the largest commercial X-ray coils the condenser capacities vary from 5 to 15 microfarads. A hasty measurement of the one I am using shows its capacity to be about 35 microfarads. To me this comparison suggests that the ordinary commercial coil would be much more efficient if its condenser were several times larger than usually made. If a coil with an insufficient condenser be operated slowly, it sparks badly at the break for reasons already given. If the speed be increased until the sparking is a minimum, it is so because the time of 'make' has been too short to allow the direct current to attain a maximum; the extra current due to self-induction is therefore less, and the small condenser can take care of it. Obviously, though, under these conditions the coil is not operating with maximum output. The time of 'make,' *i. e.*, the interval during which the primary is closed, ought to be just long enough to enable the current to reach its maximum value; this time, of course, depends on the self-induction of the coil as well as on its resistance. The time of 'break,' *i. e.*, the interval during which the circuit is open, must be long enough to enable the condenser to be charged and discharged. If the make follow the break too soon, clearly the direct current will interfere with the discharge of the condenser."

I will now pass around a few pictures illustrating some of the more recent interesting cases that have come to my attention in which X-ray examination has proved of very great assistance. (The pictures were passed, one at a time, preceded by a few words of explanation in each case.)

Another matter that it seems appropriate to bring before you this evening concerns the claims of priority in making the first electrographs by exposing a photographic plate directly between the poles of an electric machine and allowing the spark to produce its autograph. I noticed recently (see the *American X-Ray Journal*, December, 1899, p. 675) "that Dr. Wagner was the first person to get the impression by placing the sensitized plate between the sliding electrodes of a static machine." The short article from which I quote called forth in the next issue of the same journal (January,

1900, p. 693) a letter to the editor from Elmer Gates, claiming to have preceded Dr. Wagner by several weeks or more.

It really seems hardly worth while for these two gentlemen to dispute priority in taking electrographs, since your speaker, in connection with W. N. Jennings, of Philadelphia, made electrographs as early as November 20, 1889, in precisely the method described by Gates. Experiments along this line were conducted at intervals from 1889 till 1893. Electrographs of coins similar to those described in Thompson's book on X-rays, p. 19, were made by Jennings and myself on February 20, 1890. I am told that Kinraide, of Boston, several years ago showed some beautiful electrographs at the Franklin Institute, and I have not the least doubt that a dozen other experimenters performed the same experiments anywhere from five to ten years ago. Whether this be true or not, of the cases cited I have personal knowledge.

Upon one other point will I say a few words—one which is exciting considerable interest at this time among both chemists and physicists. I refer to the radiation emitted by the recently discovered radioactive substances obtained from uraninite. Early in 1898 Mme. Curie called attention to the fact that certain uranium minerals, as pitchblende, emitted Becquerel rays even more actively than uranium itself, and suggested the presence of a new substance to which this action is due. Later she and her husband isolated a new material much resembling bismuth and 400 times more active than uranium. To this substance they gave the name polonium, from Poland, their native country. Continued research upon pitchblende brought to light another substance very like barium, which at last proved to be 900 times more active than uranium. To this they gave the name radium. I have a developed photographic plate here which was exposed for several hours to the action of six little piles of uraninite, under each of which was a small piece of sheet metal about 0·005 centimeter thick. The metals were aluminum, lead, silver, gold, zinc, copper, and the plate shows roughly a difference in translucency—the aluminum seeming the least resistive, while perhaps the

lead is most so. This suggests a close relation, perhaps identity, with the X-rays. Recently the Curies are said to have separated still a third radioactive substance from pitchblende.

ERRATA.

ART.: "Fire Hazards." Parsons.

Page 173, paragraph 3 should read:

The total amount of risks in force in the United States by United States fire insurance companies and by branches of foreign companies transacting business in the State of New York, on December 31, 1898, amounted to $19,937,-661,137. The average premium was about 90 cents on each $100 of risk. The fire losses paid during that year were $71,785,247.

ART.: "Movements of Ground Water." Lyman.

Page 287, line 4; "cut," should be "cut. A linear mile could therefore yield to the cliff or cut."

Page 298, line 19 from bottom, "large" should be "larger."

Franklin Institute.

[*Proceedings of the stated meeting held Wednesday, November 21, 1900.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 21, 1900.

President JOHN BIRKINBINE in the chair.

Present, 124 members and visitors.

Additions to membership since last report, 19.

The President, in a brief address, called the attention of members to the reception to be given by the Board of Managers to the members and friends of the Institute on Saturday evening, December 8th. He called attention to the fact that a feature of the evening would be an interesting series of novel exhibits and lecture-room demonstrations under the direction of the several Sections, and that a special effort would be made to arrange a choice photographic exhibit.

Prof. F. Lynwood Garrison gave, by request, an account of a recent professional trip to Northeastern China, with some remarks on the mineral re-

sources of the Chinese Empire. He dwelt especially on the immense deposits of coal of excellent quality occurring in various parts of that country, and referred incidentally also to the occurrence, in more or less abundance, of salt, petroleum, iron, antimony and quicksilver. None of these mineral riches had as yet been worked, except in the crudest and most superficial manner, and the speaker predicted that their systematic exploitation, which must come in the immediate future, would inaugurate an industrial revolution in the far East of vast importance to the whole civilized world. Prof. Garrison's remarks were freely illustrated with lantern views.

Mr. A. S. Hamilton, of Rochester, N. Y., exhibited and described the "Standard voting machine," which is now in legalized use in a considerable number of cities and towns throughout the country. The speaker showed the *modus operandi* of the machine, and gave a demonstration of its capabilities for the service for which it is designed. The subject attracted much interest, and some discussion followed its presentation.

The Secretary exhibited and made some running comments on a series of lantern views of the buildings and grounds of the Pan-American Exposition to be held in Buffalo, N. Y., from May 1 to November 1, 1901.

The meeting thereupon adjourned.

WM. H. WAHL, *Secretary.*

COMMITTEE ON SCIENCE AND THE ARTS.

[*Abstract of proceedings of the stated meeting held Friday, October 12, 1900.*]

MR. H. R. HEYL in the chair.

(*Concluded from p. 398.*)

(No. 2090.) *Improvements in Steam Injectors.*—Strickland L. Kneass, Philadelphia, Pa.

ABSTRACT.—The improvements in question are the subject of several patents granted to applicant.

United States patent No. 376,315 (January 10, 1888) describes a form of construction of a steam injector which shall be automatic in its action under variable conditions of water supply and steam pressure, and which shall be capable of restarting itself if, for any cause, the jet should be broken, as soon as the disturbing cause is removed.

The practical results of this improvement are to make the injector automatic under widely-varying steam pressures, to enable feed-water of higher temperature to be handled, and to vary the range in quantity of water to a greater extent than was possible without this improvement.

The second improvement consists in an adjustable overflow casing large enough to permit of automatic restarting, and arranged in such a way that

the direction of the overflow discharge may be adjusted to suit the requirements of the position of the instrument.

The third improvement is for the purpose of increasing the quantity of water that can be supplied by an injector of a given size, or to increase the limiting pressure at which the maximum quantity of water can be supplied to a boiler. In other words, when an injector is taking the maximum quantity of water that can be supplied to it by the lifting discharge nozzle, the improvement is to open an additional passage through which water is supplied to the forcing nozzle.

A fourth improvement relates to the provision of an automatic valve for increasing the limiting pressure.

For the mechanical details of these several devices, reference is made to the following United States patents, viz.: No. 375,315 (January 10, 1888), No. 501,464, July 11, 1893; No. 541,620, June 25, 1895; and No. 625,267, May 16, 1899.

The committee refers to the results of several independent series of experiments made on injectors embodying the first three of these improvements, together with those made on corresponding injectors of other forms. In detail the injectors were self-starting and restarting under all the conditions of the tests, which was not the case with any others not embodying these improvements.

The range of operation was greater with this injector than with any other tested; that is, for any given pressure a certain maximum quantity of water could be delivered. The least quantity which could be delivered for the same pressure was less, and the range of operation greater with this than with any injector not using the same features.

The experiments showed also that by the use of the automatic valve for increasing the limiting pressure, the quantity of water continuously increased up to the highest pressure of these experiments (200 pounds). Certain other injectors tested had this same advantage, but none of them was restarting.

Under practical conditions, when discharging the maximum quantity of water this injector required the least quantity of steam per pound of water delivered, and it is therefore particularly valuable where the demand for steam is unusually heavy, and where it is necessary at the same time to put water into the boiler.

On the contrary, at low rates of delivery this injector requires more steam per pound of water delivered than several others, and the discharge temperature is therefore higher.

The report states the conclusion that the improvements here considered are of real value, and recommends the grant to applicant of the John Scott Legacy Premium and Medal. [*Sub-Committee.*—H. W. Spangler, Chairman; Hugo Bilgram, Francis Head.]

(No. 2127.) *Typewriting Machine.*—Remington-Sholes Company, Chicago. (Referred by the Jury of Awards of the National Export Exposition.)

ABSTRACT.—This machine is the subject of eight letters-patent of the United States, to which reference is made in the report.

The machine is described in the report as an improvement in details generally, with a few new features, over those previously known and used. (For

mechanical details, reference is made to the text of the report and to the patents filed in the case.)

The report concludes substantially as follows: Without making a summary of the various kinds of work which a typewriting machine is required to perform, we believe that on general work this machine will work as well, probably better, than other machines and that the improvements in details have added to its usefulness. It is an advance in the art and worthy of recognition because of its merit. The Edward Longstreth Medal of Merit is awarded to the inventors. [*Sub-Committee.*—J. Logan Fitts, Chairman; Luther L. Cheney, Geo. S. Cullen.]

Hydraulic Air Compressor.—Continental Compressed Air and Power Company, Philadelphia.

(Referred to the committee by the Bureau of Awards of the National Export Exposition.)

ABSTRACT.—The Committee reports that in order to determine the commercial utility of this invention it would be necessary to institute an elaborate series of tests for which no facilities are at present available. [*Sub-Committee.*—W. L. Simpson, Chairman; Wm. Copeland Furber, Coleman Sellers, Howard Rippey, John E. Codman]

(No. 2136.) *Typewriting Machine.*—George C. Blickensderfer, Stamford, Conn.

(Referred by the Bureau of Awards of the National Export Exposition.)

ABSTRACT.—This machine is the subject of a number of letters-patent of the United States to applicant, copies of which are filed with the application, and to these reference is made for description of mechanical details.

The machine under investigation is of the type wheel, direct-inking and printing class.

After detailing *seriatim* the capacity of the machine for meeting the various requirements expected of a machine of its class, the report concludes with the statement that the combination of parts in the instrument is novel, that it appears to be in a class by itself, and to represent an advance in the art of constructing typewriting machines; for which reasons the award of the John Scott Legacy Premium and Medal is recommended. [*Sub-Committee.*—J. Logan Fitts, Chairman; Luther L. Cheney, Geo. S. Cullen.]

(No. 2144.) *Station Potential Indicator or Compensator.*—Ralph D. Mershon, New York.

Reserved for publication in full.

The award of the Scott Legacy Premium and Medal is recommended to the inventor. [*Sub-Committee.*—W. M. Stine, Chairman; Charles C. Heyl.]

The meeting adopted a report on the protest of George A. Lowry, objecting to the award of the Scott Legacy Premium and Medal to Magnus Swenson for his invention of a round-lap cotton baling press. The report reaffirmed the committee's original conclusions, and the protest was accordingly dismissed. W. H. W.

[*Abstract of proceedings of the stated meeting held Wednesday, November 7, 1900.*]

MR. H. R. HEYL in the chair.

The following reports were adopted:

(No. 2074.) *Electric Meter.*—Wm. D. Marks, Philadelphia.

ABSTRACT.—An intelligible description of this apparatus is impracticable without the use of sectional illustrations. For the detailed mechanical construction and *modus operandi*, reference is made to the contents of the file wrapper of the case. The report concludes that "the apparatus is durable, commercially accurate at moderate and high loads. It would probably not be quite satisfactory to the consumer and the supply company at very low loads." [*Sub-Committee.*—H. W. Spangler, Chairman; Carl Hering, A. W. Schramm, Arthur J. Rowland, Francis B. Crocker, Wm. A. Anthony.]

(No. 2131.) *Gasoline Vapor Lamps.*—The International Heat and Power Company, Philadelphia.

ABSTRACT.—This subject was referred to the Committee by the Bureau of Awards of the National Export Exposition.

The lamp is of the class which uses gasoline vapor burned with a Bunsen flame, under a Welsbach or other mantle of rare earths, which is thereby heated to brilliant incandescence. The light is of very high intensity—650 candles—and recent tests show the consumption of gasoline to be ·35 quart per lamp per hour. Only one mantle is used in a lamp. The lamp is adapted for out-of-door service only.

The lamp is made to be enclosed in an ordinary street lantern, the gasoline tank being placed around the top of same, and when filled is made air-tight. The gasoline is fed to the burner by a tube leading from the tank, and a second tube leads down to a vessel below the lantern, in which is contained air under about 25 pounds pressure. The burner proper and generator have much the same relation as in other mantle lamps. Part of the heating flame is directed through auxiliary openings (gauze covered) against a double tube of copper lined with German silver. This is the generator in which the gasoline is vaporized. This vapor is then carried down to the base of the lamp and through a very small opening is forced up by the air pressure into the body of the burner, drawing air in with it, thence passing upward past a baffle-plate through gauzes and under the mantle, where it burns in a Bunsen flame. The lamp burns well at all atmospheric temperatures, in all kinds of weather, and is readily lighted.

This lamp differs from others of its class in that the vaporizer is detached from the burner proper and encircles it in a tube; in the absence of a needle valve to control the gasoline passing through the lamp; in the absence of packing in the tube delivering the gasoline; and in the arrangement of the baffle-plate below the mantle, to prevent the blast of air and gasoline vapor from destroying the mantle.

In these specifications this lamp is singular, and all are considered to be important. The general principles on which the operation of the lamp depends have long been known and used, and the only claims to originality reside in the judicious combination of parts used.

In recognition of the improvements embodied in this lamp, the Committee awards to the International Heat, Light and Power Company the Edward Longstreth Medal of Merit. [*Sub-Committee.*—Arthur J. Rowland, Chairman; Moses G. Wilder, Frank P. Brown, Wm. McDevitt, Charles A. Hexamer.]

Passed first reading:

(No. 2122.) *Reconstructed Granite.*—The Reconstructed Granite Company, Norristown, Pa. (Referred by the Bureau of Awards.)

(No. 2133.) *Canned Ice.*—The Misko Canned Ice Company. Dismissed for want of needful data.

W. H. W.

SECTIONS.

Abstracts of Proceedings.

CHEMICAL SECTION.—*Stated Meeting*, held Thursday, October 25, 1900. Dr. W. J. Williams in the chair.

Dr. Joseph W. Richards, of Bethlehem, Pa., read a paper "On the Utilization of Blast-furnace Gases in Gas Engines." (Published in full in the *Journal* for December.) W.

SECTION OF PHOTOGRAPHY AND MICROSCOPY.—*Stated Meeting*, held Thursday, November 1st. Dr. Henry Leffmann in the chair.

The evening was devoted to the subject of "Motion Pictures." Several members contributed illustrations of earlier forms of motion pictures. Among others, the early work of Muybridge in this field was specially referred to. Some of the modern methods were well illustrated by exhibits made by Lubin, of Philadelphia, and Jenkins, of Washington. A general discussion followed on the scientific applications of the modern methods.

F. M. SAWYER,
Secretary.

MINING AND METALLURGICAL SECTION.—*Stated Meeting*, held Wednesday, November 14th. Mr. Joseph Richards, President, in the chair.

The paper of the evening was read by Prof. F. Lynwood Garrison, entitled "Notes on the Mineral Resources of China."

MECHANICAL AND ENGINEERING SECTION AND ELECTRICAL SECTION.—Proceedings of the joint meeting held Thursday, November 16th. Mr. John F. Rowland, Jr., President of the Mechanical and Engineering Section, in the chair. There were present 98 members and visitors.

The subject for discussion was "The Electrical Distribution of Power in Workshops." The subject was opened by Prof. F. B. Crocker, of Columbia University, New York, who gave a brief sketch of the history of the development of the electric motor and exhibited on the screen a number of typical

cases showing the application of electric power for driving machine tools, printing presses and miscellaneous machinery. He enumerated the salient advantages of electric driving over the use of steam-driven line shafting.

Mr. Samuel M. Vauclain, superintendent of the Baldwin Locomotive Works, Philadelphia, gave an interesting and instructive account of the experience with the introduction of electric driving in the Baldwin Works. He gave an account of the early difficulties encountered, and of how they were at length successfully overcome. He gave a cordial endorsement of the great advantages derived from the use of the modern method.

Mr. W. H. Tapley, of the Government Printing Office in Washington, followed in similar vein, setting forth in some detail the great advantages in convenience, saving of space, and economy derived in that office from the adoption of the electric driving of the Government presses.

Mr. Gano S. Dunn, of the Crocker-Wheeler Company, spoke at some length on the limitations of the electric motor, and on the problems for the future development of the apparatus.

Dr. A. E. Kennelly, Messrs. Chas. J. Dougherty, W. C. L. Eglin and Carl Hering also contributed interesting remarks and comments. Mr. Hering dwelt specially on the relative merits of the direct and alternating current motor, claiming that the latter possessed decided advantages over the former type. Mr. Dunn took the floor in answer to Mr. Hering, claiming that in many important features the direct-current apparatus was superior to the other type.

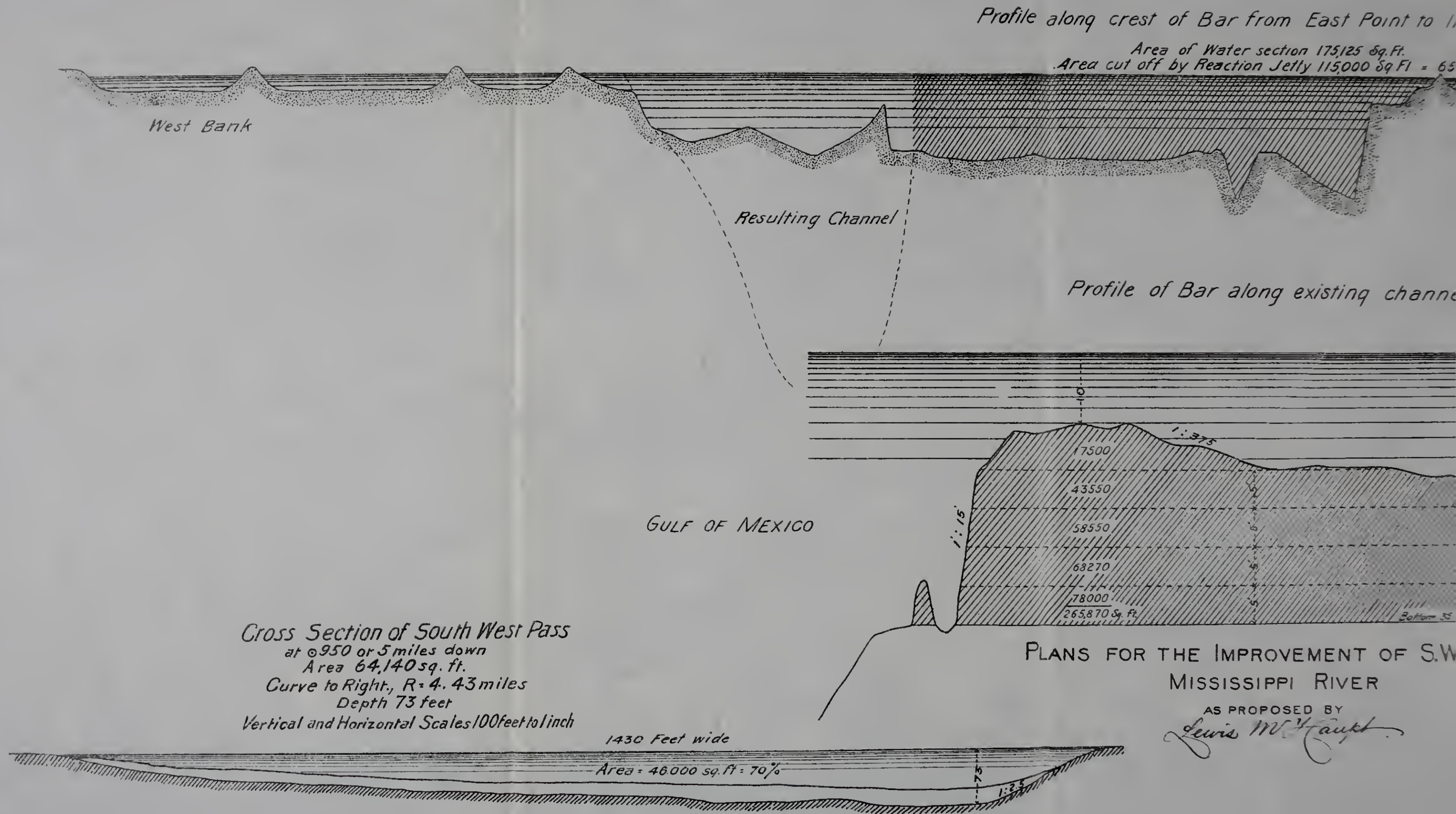
The meeting was then adjourned.

RICHARD L. BINDER,
Secretary.

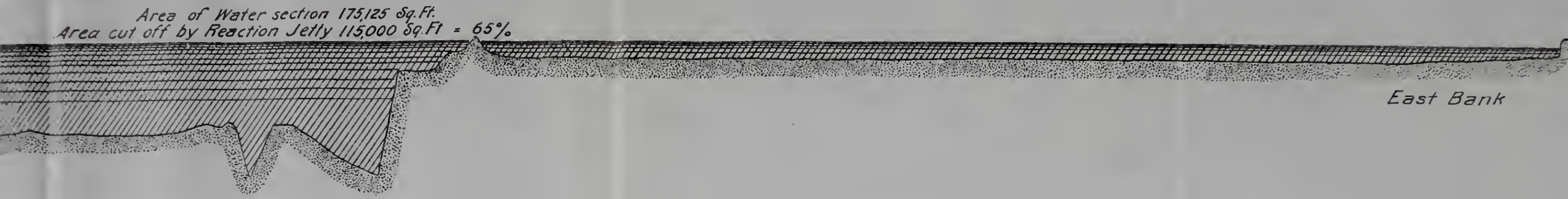
CHEMICAL SECTION.—Proceedings of the *Stated Meeting* of Thursday, November 22d. Dr. W. J. Williams in the chair. Present, twenty-four members and visitors.

Dr. Henry Leffmann read the paper of the evening, on "Methods of Micro-Chemical Analysis." The subject was freely illustrated. The paper was discussed by Dr. Meeker, who also made some interesting remarks on the "Centrifuge," with especial reference to the use of the instrument in the estimation of manganese in iron. The meeting passed a vote of thanks to Dr. Leffmann for his instructive communication, and adjourned.

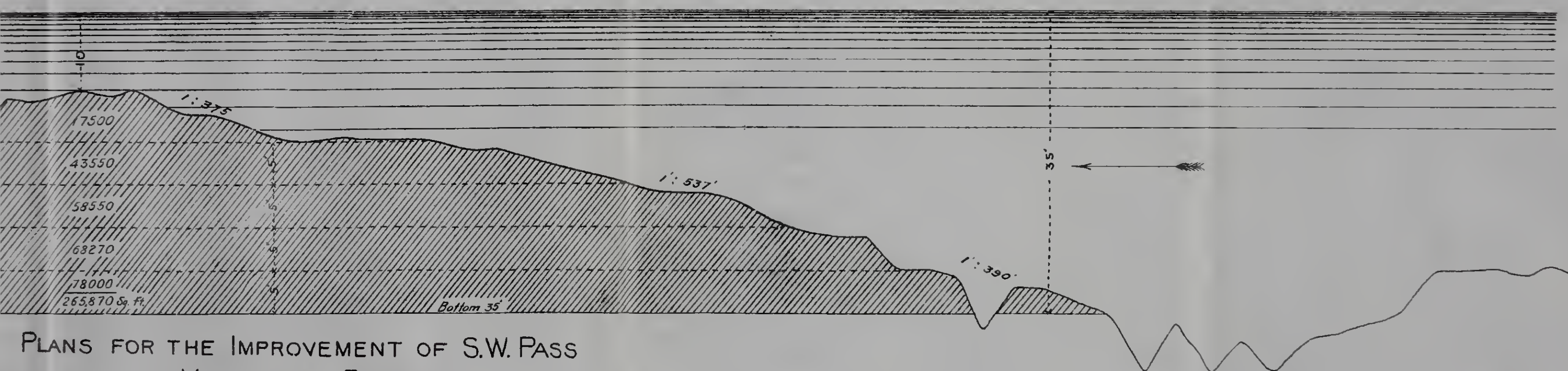
W. E. RIDENOUR,
Secretary.


Profile along crest of Bar from East Point to
Area of Water section 175,125 Sq. Ft.
Area cut off by Reaction Jetty 115,000 Sq. Ft. = 65
West Bank
Resulting Channel
Profile of Bar along existing channe
1:375
17500
43550
58550
68270
78000
265,870 Sq. Ft.
1:15
Gulf of Mexico
Plans for the Improvement of S.W
Mississippi River
as proposed by
Lewis M. Haupt
Cross Section of South West Pass
at ⊙950 or 5 miles down
Area 64,140 sq. ft.
Curve to Right., R = 4.43 miles
Depth 73 feet
Vertical and Horizontal Scales 100 feet to 1 inch
1430 Feet wide
Area = 46000 sq. ft = 70%
73
1:2.5

…file along crest of Bar from East Point to Inner Lump



Profile of Bar along existing channel



PLANS FOR THE IMPROVEMENT OF S.W. PASS
MISSISSIPPI RIVER

AS PROPOSED BY
Lewis M. Haupt

Horizontal scale 1250' : 1"
Vertical scale 10' : 1"